AD______________

Award Number: DAMD17-96-1-6124

TITLE: Characterization of Emissions from Heaters Burning Leaded Diesel Fuel in Unvented Tents

PRINCIPAL INVESTIGATOR: Yung-Sung Cheng, Ph.D.

CONTRACTING ORGANIZATION: Lovelace Biomedical and Environmental Research Institute, Incorporated
Albuquerque, New Mexico 87185

REPORT DATE: June 1999

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release;
distribution unlimited

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1999	Final (7 Jun 96 - 31 May 99)

4. TITLE AND SUBTITLE
Characterization of Emissions from Heaters Burning Leaded Diesel Fuel in Unvented Tents

5. FUNDING NUMBERS
DAMD17-96-1-6124

6. AUTHOR(S)
Yung-Sung Cheng, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lovelace Biomedical and Environmental Research Institute, Incorporated
Albuquerque, New Mexico 87185

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The human exposure to aerosols from unvented heaters in tents was simulated, so that the contribution of this exposure to the Gulf War Syndrome could be estimated. Exposures to particulate matter and combustion gases (CO, NO, and SO_2) were estimated with three types of portable kerosene heaters and three fuels. The airborne concentration was also monitored continuously with a real-time monitor. The aerodynamic particle size distribution measured by a cascade impactor showed a major peak between 0.1 – 1 μm. The air exchange rate ranged from 1 to 3.5 hr^{-1} when the tent doors were open and closed. The air exchange rate and the type of fuel and heater were very important factors in determining the pollutant concentrations inside the tent. Chemical analyses showed that major species in the particles were sulfate, nitrates, ammonium, and elemental and organic carbon. The particle concentration and distribution results were used in the NCRP model to calculate the particle generation rate from heaters and the dose deposited in human lungs. The results showed that the particles deposited in the lung ranged from 0.31 to 0.97 mg for a 10-hr stay in the tent with various heaters and fuels.

14. SUBJECT TERMS
Gulf War Illness Unvented Heater, Inhalation Dose, Army Tent

15. NUMBER OF PAGES
74

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the U.S. Army.

____ Where copyrighted material is quoted, permission has been obtained to use such material.

____ Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

__*ps*__ Citations of commercial organizations and trade names in this report do not constitute an official Department of Army endorsement or approval of the products or services of these organizations.

____ In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and use of Laboratory Animals of the Institute of Laboratory Resources, national Research Council (NIH Publication No. 86-23, Revised 1985).

____ For the protection of human subjects, the investigator(s) adhered to policies of applicable Federal Law 45 CFR 46.

____ In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institutes of Health.

____ In the conduct of research utilizing recombinant DNA, the investigator(s) adhered to the NIH Guidelines for Research Involving Recombinant DNA Molecules.

____ In the conduct of research involving hazardous organisms, the investigator(s) adhered to the CDC-NIH Guide for Biosafety in Microbiological and Biomedical Laboratories.

[signature] June 23 1999

PI - Signature   Date

TABLE OF CONTENTS

INTRODUCTION

Approximately 700,000 U.S. military personnel served in the Persian Gulf conflict during 1990 and 1991. As a result, 85,000 Gulf War veterans participated in clinical programs through 1997. A significant proportion of the participants (20–30 %) was diagnosed as having a "mystery illness" or "Gulf War Syndrome" (CDC, 1999). Manifestations of this syndrome include arthralgia, weakness, fatigue, headache, memory loss, skin rashes, and hair loss (IOM, 1995). Various suspected causes include chemical and biological warfare agents, fumes from leaded and unleaded fuels, smoke from burning oil wells, illicit substitutes for alcohol, and illegal drugs.

Little information is available with which to study possible links between environmental exposures and the Gulf War Syndrome. While these exposures may have been important, the data needed for sound epidemiological studies are very limited. Major contributions to air pollution during this time included oil-well fires in Kuwait, fumes from cook stoves and heaters, pesticides, and naturally occurring pollutants such as sand, dirt, and fauna (CDC, 1999). Most of these environmental factors have been studied and evaluated to some degree, except the exposures to pollutants produced from unvented heaters in tents. To fully characterize these exposures and the resulting potential health risk to the troops, all pathways of exposure must be evaluated.

Various types of portable space heaters are widely used in offices and homes. Tu and Hinchliffe (1983) studied the emissions from five portable space heaters, including three conventional electrical heaters, one quartz electrical heater, and one kerosene heater. Their results indicated that most aerosols produced are in the ultrafine particle range, and the aerosol concentration in an unvented chamber can be as high as 330 $\mu g/m^3$ from a kerosene heater used for 1 h. Particles are primarily composed of carbon black and chromium. The gas phase was not studied. Traynor *et al.* (1985) and Relwani and Moschandreas (1986) have reported on emissions from gas-fired space heaters. The primary pollutants were carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) with very low mass concentrations of ultrafine particles. On the other hand, emissions from burning liquid fuels can be substantial in terms of both gas pollutants and particles. For instance, emissions from unvented kerosene space heaters can contribute to indoor air particulate concentrations in excess of 20 $\mu g/m^3$ over background level (Leaderer and Boone, 1990) and over 300 $\mu g/m^3$ in a sealed chamber (Tu and Hinchliffe, 1983). The space heaters can also emit organic compounds such as polycyclic aromatic hydrocarbons (PAHs), in addition to CO_2, CO, NO and/or NO_2 (NO_X), and sulfur dioxide (SO_2) (Leaderer and Boone, 1990; Traynor *et al.*, 1990). Mumford *et al.* (1992) showed that semivolatile and particle-bound organic emissions from kerosene heaters are mutagenic. The use of kerosene heaters and atmospheric conditions, such as open doors and windows, can affect indoor air quality (Setiani, 1994).

The purpose of this study was to simulate human exposure to aerosols produced by unvented heaters in tents used during the Gulf War, so that the contributions of these exposures could be estimated. The objectives included:

1. Physical and chemical characterization of aerosols produced by heaters that burned fuels in an unvented tent.
2. Estimation of exposure to particulate matter (PM), combustion gases (such as CO, NO_x, and SO_2), and other compounds (such as lead, PAHs, etc.).
3. Elemental, salt, and carbon analyses from the PM-2.5 and PM-10 filter samples.
4. The calculation of particle and gas generation rates from different types of heaters and fuels.
5. A particle dosimetry study for different types of heaters and fuels in the tent during a certain time.

The first step of the project was to set-up the experiments and to gather initial data from early tests. We had extensive discussions with several Army laboratories on tents, tent heaters (US Army, Natick Research Development and Evaluation Center), and fuels (Fuels & Lubricants Technology Team, Mobility Technology Center - Fort Belvoir). Based on these discussions, it was determined that the unvented heaters most likely used in the Gulf War were commercial units that burned kerosene and aviation fuels, primarily JA-1 and JP-8 fuels which are kerosene-based and have similar compositions. The standard Army heater is vented outside of the tent and is much less a concern for inhalation health effects. A used Army tent, an Army tent heater, and two kinds of kerosene heaters were then purchased. The tent was set up inside a clamshell structure to better control the environmental conditions, and various pieces of instrumentation including samplers for particles, gases, and vapors were tested. We obtained the initial results with burning the commercial 1-K kerosene.

Based on results of the initial experiments, several instruments were added to measure both particle and gas concentrations in the second step of the project. From these instruments, the exposure to particles less than 10 μm and 2.5 μm (PM-10 and PM-2.5) and the distribution of ultrafine particles can be estimated. The real-time particle and gas concentration can also be monitored. The experiments were run under various conditions during the second year of the project. Another kerosene heater was added for a total of three types of heaters in the experiments. Two more fuels, JA-1 and JP-8, were added, as well as three different air exchange rates, when the tent-doors were open, closed, and half-opened. Complete experimental results were obtained including particle concentrations and distributions, gas concentration profiles, elemental and salt concentrations on the filter samplers, and carbon concentrations on the filters.

As the third step of the project, the tent was moved to outside of the clamshell to simulate the actual environmental conditions of the Gulf War. The same measurements were done as inside the clamshell structure while the tent doors were closed.

Finally, after all of the experiments, the particle and gas generation rate with the particle and gas concentration profiles were calculated for different types of heaters and fuels. Assuming the Army personnel stayed in the tent for 10 hours each night, the gas inhalation dose and the particle deposition dose were also calculated.

This report presents all results obtained at each step of the project, including the data from the 1997 and 1998 annual reports.

BODY OF THE REPORT

ASSUMPTIONS

The primary purpose of this study was to characterize, physically and chemically, the aerosols produced from unvented heaters. These aerosols are generally formed from vapor condensation of the burning fuel and from residuals of incomplete combustion. Two assumptions were made: soldiers were primarily exposed to emissions from unvented heaters in tents, and the types of fuel, heaters, and the air exchange rate were the major factors influencing the emission characteristics and, therefore, the exposure.

EXPERIMENTAL METHODS

Tent, Heaters, and Fuels

A vinyl-backed canvass Army tent (GP medium, 975 cm x 488 cm) was set up inside a clamshell structure. The temperature, relative humidity (RH), and barometric pressure were same as outdoors, but the wind condition was relatively stable. Therefore, the air exchange rate within the tent could be better controlled inside the clamshell than outside. After the experiments inside the clamshell, the tent was moved outdoors to simulate the actual conditions during the Gulf War. The volumes of the tent and clamshell structure were estimated, based on their geometries, to be 106 m^3 and 5000 m^3, respectively, as shown in Figure 1 (see Appendix I for all figures and tables cited in the text). Figures 2 and 3 show photographs of the tent and the control panel inside and outside the clamshell. Because a number of commercial unvented heaters were widely used in tents during the Gulf War, three kinds of unvented heaters on the market were tested: two each of the convection-type heaters (RMC-95, RMC International, Denver, CO, rated at 22,300 Btu per h; and Omni-105, Toyotomi U.S.A., Inc. rated at 23,000 Btu per h) and two radiant heaters (Model AWHR-1101, Cans Unlimited, Inc., Greer, SC, rated at 10,000 Btu per h). The heaters were operated inside the tent to simulate their use during the Gulf War. Because the primary fuel used during this war was jet fuel, 1-K kerosene (Parks Co., Fall River, MA), JA-1 jet fuel, and JP-8 jet fuel were used in these experiments. Table 1 lists the heater specifications and the fuel characteristics.

Sampling Instruments

Because the aerosols produced by the heaters were mostly in the fine and ultrafine particle size range, and the vapor-phase emission contained PAHs and lead, the following aerosol sampling instruments were selected for this study:

1. Six PEMs (Personal Environmental Monitor, Model 200, MSP Corporation, Minneapolis, MN) were used to determine the particulate matter, three for PM-10 and three for PM-2.5
2. A 10-stage MOUDI (Micro-Orifice Uniform Deposit Impactor, Model 110, MSP Corporation, Minneapolis, MN) was used for aerosol size distributions between 0.056 - 18 μm.
3. A DataRAM real-time aerosol monitor (Monitoring Instruments for the Environment, Inc., Bedford, MA) was used to measure the particle concentration in real time. The particle size range of maximum response is from 0.1 μm to 10 μm. The concentration measurement range of the DataRAM is from 0.1 $\mu g/m^3$ to 399.99 mg/m^3.

Two kinds of filters, Teflon and quartz, were used in the PEM samplers. After the samplers were weighed for PM-10 and PM-2.5, they were used for elementary chemical analysis, which was done at the Desert Research Institute in Reno, NV. Gaseous emissions were also monitored using the following instruments:

1. CO infrared analyzer (Model 865 Beckman Instruments, Fullerton, CA)
2. NO_X chemilumination analyzer (Model 8440, Monitor Labs, San Diego, CA)
3. Multi-Gas Monitor (Multiwarn II, Draeger Safety, Inc., Pittsburgh, PA) which measures multiple gases, such as CO, SO_2, NO_2, and PAHs.

Air Exchange Rate

The air exchange rate in the tent is a major factor in determining the pollutant concentrations inside the tent. The exchange rate was determined using a trace gas method (Cheng *et al.*, 1995). A predetermined amount of sulfur hexafluoride (SF_6) was released into the tent, and the SF_6 concentration was monitored using an Autotrac monitor (Model 101, Lagus Applied Technology, San Diego, CA). The SF_6 concentration can be fitted into the following equation (Cheng *et al.*, 1995):

$$C = C_0 \, exp(-\lambda_v \cdot t), \tag{1}$$

where C and C_0 are SF_6 concentrations in time t and 0, and λ_v is the air exchange rate (h^{-1}). This equation can also be used to estimate the volume of SF_6 in the tent. By injecting a known volume of SF_6 (V_{SF6}) and from the fitted value of C_0, the tent volume (V_{tent}) can be determined by:

$$V_{tent} = \frac{V_{SF6}}{C_0}. \tag{2}$$

SAMPLING PROCEDURES

Before the experiments began, the particle concentrations of PM-2.5 and PM-10 at various positions in the tent were tested. Figure 4 shows the positions of the PEMs, and Table 2 presents the concentration ratio of the specific points (B,C,D,E) and the central point (A). The results indicate that the particle concentration in the center of the tent was the same as those in the corners. We assumed that the central point is the representative point in the tent. Therefore, during the experiment, all equipment was located around the central point. Figure 5 is a schematic of the experimental set-up of sampling instruments used in the tent. Gas analyzers were calibrated and the filter and impactor substrates weighed. The ventilation rate within the tent was measured using the trace gas method as just described. A trace amount of SF_6 in the compressed gas cylinder was released to give an initial concentration of between 10-100 ppb in the tent. Changes in the ventilation rate were investigated under various conditions when the tent-doors were open, closed, or half-open.

The gas and aerosol monitors were turned on, then the heaters were ignited (usually two identical heaters were used in order to provide enough heat). The heaters were well maintained. Aerosol samples were taken by using the filters in the PEMs and the MOUDI. Real-time aerosol concentration and size distribution were measured by using the DataRAM. CO, NO, SO_2, and total hydrocarbon concentrations were monitored continuously. The heaters were turned off after 4 hours, but the monitoring continued for another hour.

The aerosol mass collected on the filters and the substrates was determined by weighing them before and after each run using a Cahn-31 electrobalance (Cahn Instruments Inc., Cerritos, CA). The filter samples were analyzed for chemical elements at the Desert Research Institute. The time-averaged aerosol size distributions were calculated from the MOUDI weight data and the stage effective cut-off diameters.

All sampling probes were positioned between 48-60 cm (19-24 inches) off the ground (see Figure 5) close to the breathing zone of a sleeping person. Temperatures were measured at two points in the tent: at the center with heights of 60, 152, and 183 cm (24, 60, and 72 in) and at the corner with a height of 60 cm.

ELEMENTAL ANALYTICAL METHODS

Filter Testing

Quartz fiber and Teflon membrane filters must be tested before use to ensure their adequacy for collecting samples. Quartz filters also require pre-firing to reduce organic carbon (OC) concentrations to acceptable levels. Teflon and quartz filters were tested before use in the present study.

The quartz filter pre-firing, acceptance-testing, and chemical-analysis procedures are widely used in many air-quality studies as recommended by the U.S. EPA (1994a) for sampling particulate matter. All filters were handled and analyzed in accordance with Desert Research Institute Standard Operating Procedures that provide step-by-step instructions for sample handling, instrument calibration, sample analysis, and data validation.

Pre-Firing the Quartz Filter

Organic carbon remaining on quartz filters after manufacture and absorption of organic vapors during normal storage and handling resulted in OC concentrations of variable and unacceptably high levels. Pre-firing reduced carbon concentrations to acceptable levels of less than 1.5 $\mu g/cm^2$ OC and 0.5 $\mu g/cm^2$ elemental carbon (EC).

Quartz filters were pre-fired in air for at least 3 h at ~900°C. After cooling, each filter was examined over a light table for discoloration, pinholes, creases, or other defects.

Defective filters were discarded. Filters were sealed and stored in a freezer immediately after pre-firing and inspection. Filter lots that did not pass the acceptance test for carbon were either fired and tested again, or discarded.

Acceptance Testing

Filters required representative chemical analyses before use to ensure they were not contaminated. Several important air-quality studies have been compromised due to excessive blank levels discovered after samples were collected.

Two percent of the filters from each lot were subjected to chemical analysis to verify that pre-established specifications were met. Acceptance criteria were chosen based on concentrations that would not interfere with normal ambient or source samples.

Two percent of the Teflon filters in each lot were submitted for elemental analysis by x-ray fluorescence (XRF) before sampling. The acceptance criterion was twice the Protocol A detection limit (Watson *et al.*, 1996). If concentrations of all elements were less than or equal to twice the detection limit, the lot passed.

Two percent of the quartz filters in each lot were subjected to carbon and ion analyses after pre-firing and visual acceptance tests. Acceptance criteria were 1.5 $\mu g/cm^2$ OC, 0.5 $\mu g/cm^2$ EC, and 1 μg/filter for chloride, nitrate, sulfate, and ammonium. If the concentration for any species was higher than these limits, the entire lot failed. These lots could be pre-fired and tested again.

X-Ray Fluorescence Analysis

X-ray fluorescence analysis was performed on Teflon-membrane filters for the following elements: Ag, Al, As, Au, Ba, Br, Ca, Cd, Cl, Co, Cr, Cu, Fe, Ga, Hg, In, K, La, Mn, Mo, Ni, P, Pb, Pd, Rb, S, Sb, Se, Si, Sn, Sr, Ti, Tl, U, V, Y, Zn, and Zr using an energy-dispersive XRF (EDXRF) analyzer. EDXRF analysis (Dzubay and Stevens, 1975; Jaklevic *et al.*, 1977) produces a spectrum of peaks or "lines" superimposed on a smoothly varying background. The energy of each line is characteristic of a particular element, and the intensity of each line is proportional to the concentration of the element in the sample.

X-ray fluorescence analyses were performed on a Kevex Corporation Model 0700/8000 or a Kevex 0700/IXRF EDXRF analyzer using a side-window, liquid-cooled, 60 keV, 3.3 milliamp rhodium anode x-ray tube and secondary fluorescers. The analysis was controlled, spectra were acquired, and elemental concentrations were calculated by software implemented on an LSI 11/23 microcomputer (0700/8000 model) or a Pentium PC (0700/IXRF model). Each sample was analyzed under five separate excitation conditions to optimize the detection limits for the specified elements.

Several blank filters from the same manufacturing lot as the sampled filters were analyzed along with the exposed filters. An average blank spectrum was constructed and used for spectral background subtraction of the exposed filters. Net peak intensities were converted to concentration after subtracting the spectral background and any peak overlap interference present. The precision of the concentration measurement was estimated from the counting statistics for each peak.

Filter Sectioning and Extraction

Quartz filters identified for both carbon and ion analyses were sectioned beforehand. Each quartz-fiber filter was cut in half with a precision alignment jig attached to a paper cutter. The blade was cleaned between filter cuttings. One half of the filter was returned to its Petri dish and stored (refrigerated) for subsequent carbon analysis. The other half of the filter was placed in a 16 x 150 mm polystyrene extraction vial with a screw cap. The extraction tubes were placed in tube racks, and 10 ml of deionized-distilled water was added. The extraction vials were capped and sonicated for 60 min, then shaken for 60 min. The ultrasonic bath water was monitored to prevent temperature increases from the dissipation of ultrasonic energy in the water. After extraction, these solutions were stored under refrigeration prior to analysis. Water-soluble chloride, nitrate, sulfate, and ammonium were obtained by analysis of these extracts.

Thermal/Optical Reflectance Carbon Analysis

The thermal/optical reflectance method (Huntzicker *et al.*, 1982) measures OC and EC. This method is based on the principle that different types of carbon-containing particles are converted to gases under different temperature and oxidation conditions.

As with XRF, 10% of the samples were subjected to replicate analysis. Samples were re-analyzed if replicate results were not within ±10% or ± 1 $\mu g/cm^2$ for samples with < 10 $\mu g/cm^2$ of carbon. Measurement precision was determined by calculating the average fractional difference between the original and replicate measurements. For sample batches with large concentration differences, precision may be determined separately for two or three different concentration ranges.

Ion Chromatography and Automated Colorimetric Analysis

Water-soluble chloride (Cl^-), nitrate (NO_3^-), and sulfate ($SO_4^=$) were measured with the Dionex 2020i (Sunnyvale, CA) Ion Chromatograph. In ion chromatography, an ion-exchange column separates the sample ions in time for individual quantification by a conductivity detector (Small *et al.*, 1975; Mueller *et al.*, 1978; Small, 1978). Prior to detection, the column effluent enters a suppressor column where the chemical composition of the component is altered, resulting in a matrix of low conductivity. The ions were identified by their elution/retention times and quantified by the conductivity peak area. Approximately 2 ml of the filter extract was injected into the IC. The resulting peaks were integrated, and the peak integrals were converted to concentrations using calibration curves derived from solution standards.

The Technicon (Tarrytown, NY) TRAACS 800 Automated Colorimetric System (AC) was used to measure ammonium (NH_4^+) concentrations by the indolphenol method. Each sample was mixed with reagents and subjected to appropriate reaction periods before submission to a colorimeter. According to Beer's Law, the absorbency of the liquid is related to the amount of the ion in the sample. This absorbency was measured by a photomultiplier tube through an interference filter, specific to the species being measured.

Ten percent of the samples were subjected to replicate analyses. Samples were re-analyzed if replicate results were not within ±10% (±20% for concentrations < 0.15 mg/ml, or ±30% for concentrations < 0.10 mg/ml). Measurement precision was determined by calculating the average fractional difference between original and replicate measurements. For sample batches with large differences in concentration, replicate precision may be determined separately for two or three different concentration ranges.

DOSE CALCULATION

To calculate dose, the respiratory pattern should be determined. It was assumed that military personnel slept for 8 hours and rested for 2 hours in the tent each evening during the Gulf War. The deposition pattern and fraction of inhaled particles in the human respiratory tract can be estimated from particle concentrations in each size fraction and the breathing pattern using the NCRP (National Council on Radiation Protection and Measurements) Lung Dosimetric Model (NCRP, 1997). Figure 6 shows the schematic representation of the human respiratory tract as defined by the NCRP model. The human respiratory tract is divided into three anatomical regions. The head airway including the naso-oro-pharyngo-laryngeal (NOPL) region is the entry to the respiratory tract and the first defense against hazardous inhaled material. The tracheobronchial (TB) tree includes the trachea and 16 generations of branching airways. Gas exchange takes place in the pulmonary region (P). Particles deposit in the lung by inertial impaction, sedimentation, diffusion, and electrostatic mechanisms. Deposition equations have been developed for different mechanisms in all three anatomical regions (NCRP, 1997). Theoretical predictions of deposition fractions calculated from the NCRP model have been verified with experimental data obtained in human volunteers and an airway replica (NCRP, 1997). According to an NCRP report (NCRP, 1997), the tidal volumes (VTs) are 625 ml and 750 ml for sleeping and rest, respectively, and the breathing frequency (f_R) is 12 min^{-1} in both cases. The normal augmenters (100% nose breathing) and mouth breathers (70% nose breathing and 30% mouth breathing) were considered in the calculation of the deposition dose. The deposition doses were calculated in the NOPL, TB, and P regions for the specific particle size.

EXPERIMENTAL RESULTS

Twenty-seven test runs were made under the various conditions inside the clamshell, and nine runs were made outside the clamshell. The air exchange rate varied from 1.0 to 3.6 /h. Because the air exchange rate was difficult to control exactly, the average values for open, half-open, and closed doors were used in the comparison. Figures 7 – 16 show one test using the JA-1 fuel and the AWHR-1101 heater as examples. The overall results for these 36 runs are shown in Appendix II.

Tent Volume and Air Exchange Rate

The tent volume can be estimated from the SF_6 test. SF_6 (3 ml) was injected into the tent. From fitting equation 1 to the concentration decay data, the initial concentration C_0 was estimated (29.6 ± 5.9 ppb) and the tent volume calculated following equation 2. Based on five separate tests, the estimated tent volume was 101.4 ± 20.2 m^3. This volume is within ± 5% of the calculated volume of 106 m^3.

The air exchange rate in the tent was adjusted by closing and opening the doors. Figure 7 shows the SF_6 concentration profile from an experiment. The fitted curve was C = 30.926exp(-0.0227t). The interception of C_0, 30.926 ppb, was the initial concentration, and the air exchange rate (λ) was 0.0227 min^{-1} (1.36 h^{-1}). In principle, both gas and particle concentrations decrease when the air exchange rate increases. The air exchange rate was between 1.0 and 1.4 h^{-1} when the tent doors were closed. This rate is still higher than the mean indoor exchange rate, 0.53 h^{-1}, of homes in the U.S. (U.S.EPA, 1996a). Figure 8 shows one set of data at different air exchange rates but under the same experimental conditions. The same trend as expected can be seen: all concentrations decreased, while the air exchange rate increased (Fig. 8).

Temperatures and Relative Humidity

Figure 9 shows the increase in temperature as a function of time, suggesting a rapid rise after the heaters were ingited and a rapid decline after the heaters were turned off. The temperature was raised with the height of the thermocouple. The temperature at the center of the tent was higher than that at the corner with the same height. Figure 10 shows the decrease in RH as a function of time.

Gas Concentrations

Figures 11-13 show the concentration profile of CO, NO, and SO_2, and Figure 14 shows the mean concentrations of these gases at the same air exchange rate when the various heaters and fuels were used.

Because the combustion was incomplete after the heater was ignited, the CO concentration rose quickly to reach the maximum value. Then it decreased during the time of the burning and reached a relatively stable value (Fig. 11). Different types of heaters and fuels can also result in different CO concentrations (Fig. 14). The CO concentrations always appeared to be high with the AWHR heater and any of the fuels. For the RMC and Omni heaters, the lowest CO concentration was obtained with the JA-1 fuel. The Omni heater showed the lowest CO concentration when burning JA-1 and JP-8 fuels, but the highest concentration for 1-K fuel. In our experiment, the maximum peak value for CO was 9.4 ppm, and this value was held for a minute. The average value for CO over 4 h ranged from 0.01 to 1.8 ppm for different types of heaters and fuels. These values are below the National Ambient Air Quality Standard (NAAQS), 9 ppm for 8 h and 35 ppm for 1 h (U.S.EPA, 1994b), and the Threshold Limit Values (TLVs) for the workplace (ACGIH, 1998), 25 ppm time-weighted average.

Concentrations of NO_2 in the experiments were very low, in most cases below the detection limit. However, the NO gas was significant during the tests. The concentration profile of NO in the tent differed from the CO concentration. The NO was highly concentrated when the temperature was high. Therefore, it did not increase sharply like CO. Figure 12 shows that about 10 minutes after the heater was started, the NO concentration in the tent was same as at ignition. The NO concentration increased as the temperature increased until the maximum value was reached. Like the CO concentration, the NO concentration also changed when different heaters and fuels were used (Fig. 14). It appears that the fuel was not the important factor in the NO concentration. The AWHR heater showed the lowest concentration for all three fuels. A higher concentration was found for the RMC and Omni heaters, because their heat output values were more than twice those of the AWHR. Because NO is an unstable gas which reacts to NO_2 very quickly, our experimental data were compared with a national standard for NO_2. The average NO value measured in the present study ranged from 0.01 to 1.5 ppm for different types of heaters and fuels.

The SO_2 concentration profile (Fig. 13) seems similar to that of the NO. The SO_2 concentration profile reached its peak when the temperature increased to the maximum and decreased very quickly after the heaters were turned off. The effect of the heater and fuel on the SO_2 concentration is also shown in Figure 14. The RMC heater emitted little SO_2, whereas the Omni heater produced high levels of SO_2. The JP-8 fuel produced less SO_2 than the other two fuels. The average measurement of the SO_2 ranged from 0 to 1.5 ppm for different types of heaters and fuels. The value of SO_2 concentration is over the NAAQS (U.S.EPA, 1996b), 0.14 ppm for 24 h, but lower than the TLV, 2.0 ppm time-weighted average.

Particle Concentration and Distribution

Figure 15 shows the particle mass concentration as a function of time and suggests that concentrations peaked after the heaters were turned on and off. Figure 16 shows the particle size distributions measured by the MOUDI cascade impactor at two different air exchange rates when two AWHR heaters and the JA-1 fuel were used. A peak was found at around 0.2 or 0.3 μm, which means that most particles from the heaters were ultrafine. Bimodal distributions with another mode at around 10 μm were also found when the air exchange rate was high. These large particles indicated the effect of the outside air when tent doors were open. Figure 17 gives the PM-10 and PM-2.5 values when different types of heaters and fuels were used and indicates that more particles were produced with the 1-K fuel and fewer particles with the JP-8 fuel. The PM-10 values ranged from 26 $\mu g/m^3$ (open doors) to 854 $\mu g/m^3$ (AWHR heater, closed doors), whereas PM-2.5 values ranged from 16 $\mu g/m^3$ (open doors) to 678 $\mu g/m^3$ (closed doors). Most values determined when doors were closed were larger than the NAAQS (U.S.EPA, 1997), 150 $\mu g/m^3$ (PM-10) and 65 $\mu g/m^3$ (PM-2.5) for 24 hours. These data, however, are still within the TLVs for occupational exposure of inert PM (ACGIH, 1998), 3 mg/m^3 time-weighted average. The ratios of PM-2.5 and PM-10 concentration were calculated for each test. The volume of ratios ranging between 0.62 and 0.97 indicates that the heaters produced fine and ultrafine particles.

Chemical Elemental Analysis

Twenty-seven test runs were made under the various conditions. The air exchange rate varied from 1.0 to 3.6 /h. When the tent doors were open or half open, the air exchange rate was high, so that the few particles that collected on the filters were not sufficient for analysis. Only nine tests (each for different heaters and fuels) were available for elemental analysis when the tent doors were closed and the air exchange rates were between 1.0 and 1.4 h^{-1}.

Results of the carbon and salt analyses for both PM-2.5 and PM-10 particles were obtained by analyzing the quartz filters. The concentrations of carbon and ions for the PM-2.5 were smaller than those for the PM-10 in most cases. Except for the nitrate level, the carbon and ion concentrations for the PM-2.5 were just slightly lower than that for PM-10, which indicates that the samples from the tent consisted mostly of fine particles. Figures 18 - 21 show the concentrations of the EC, OC, $SO_4^=$, NO_3^-, and NH_4^+ from the different heaters and fuels. The EC concentrations always appeared to be high with the AWHR heater burning all fuels (Fig. 18). The OC concentration also appeared to be high with the AWHR heater, but only with the 1-K and JP-8 fuels. The OC concentration from the AWHR heater burning JA-1 fuel was almost the same as with the Omni heater. The EC results agreed with the results of the CO concentration for the 1-K and JA-1 fuels in terms of relative concentrations for all three heaters (Fig. 14). The RMC heater burning JP-8 fuel emitted the highest CO gas concentration among the three fuels, but the lowest OC and EC concentrations. The ratio of the EC and OC concentrations of PM-2.5 and PM-10 particles were 1.04 ± 0.24 and 1.07 ± 0.24 (mean $\pm$ SD), respectively. These results indicate that the carbon was associated with particles smaller than 2.5 μm.

The $SO_4^=$ concentration for both PM-2.5 and PM-10 particles (Fig. 19) showed the lowest value with the RMC heater burning any of the fuels. The JP-8 fuel produced less sulfate concentration than the other two fuels for all three heaters. For most fuel types and heaters, the sulfate concentrations for PM-10 and PM-2.5 were similar (0.99 ± 0.06). However, for the Omni heater and the JP-8 fuel, the concentration for PM-10 particles was much higher than that for PM-2.5 particles. The reason for this strange result is unknown. Measurements of sulfate concentration were consistent with measured SO_2 gas concentration. The sulfate concentration was the highest among the ions, which indicates that SO_2 was one of the main gases emitted from the heaters.

Figure 20 shows very low NO_3^- concentrations near or below the limit of detection (0.21 $\mu g/m^3$). Therefore, the NO_3^- concentrations may not be sufficiently accurate for the comparison.

The NH_4^+ was also emitted from the heaters. Figure 21 shows that the 1-K fuel produced a high concentration of NH_4^+, and the JA-1 and JP-8 fuels produced almost the same emission with the different heaters. With the 1-K fuel, the AWHR heater produced the highest NH_4^+ concentration. The sum of the ions and carbon concentration should be the same as the mass concentration in the same filter. As expected, the average NH_4^+ concentration ratio for PM-2.5 and PM-10 particles is also around 1 (0.97) with a standard deviation of 0.11.

Figure 22 shows the comparison of the sum of the $SO_4^=$, NO_3^-, NH_4^+, and carbon concentration and the total mass concentration when the air exchange rate ranged from 1.0 to 1.4 h^{-1} and the tent doors were closed. The particle concentration is always higher than the sum of the ions and carbon concentration. The ratio of the carbon and salt concentrations and the total mass concentrations was 0.63 ± 0.18.

The elemental results of the XRF on Teflon-membrane filters with different heaters and fuels (Figs. 23 - 25) show that the significant element is sulfur. The sulfur concentration in the filter of the PM-2.5 samplers was lower than that of the PM-10 samplers, but by very little in most cases. This indicates that the sulfur was confined to the small particles; very little sulfur adhered to or coagulated with the large particles (over 2.5 μm). Among the three types of heaters, the AWHR produced a high concentration of sulfur, and the 1-K fuel emitted the largest amount of sulfur. The most popular element in the soil, silicon, was the second highest concentration (Figs. 23 - 25). The filter of the PM-10 sampler contained much more silicon than did the PM-2.5 sampler. This result indicates that the large particles from the ambient air also affected the environment in the tent, although it was sealed very carefully. Other elements, Al, Ba, Ca, Cd, Cl, Cr, Cu, Fe, K, La, Pb, Sb, Ti, and Zn, were also detected in the filters of either PM-10 or PM-2.5 samplers, or both. These elements were probably from the ambient air as well (U.S. EPA, 1996a).

CALCULATION OF THE GENERATION RATE AND EMISSION FACTOR

Aerosol and Gas Concentration Profiles in the Tent

Aerosol and gas dynamics in the tent were investigated to determine the factors that could influence the generation and clearance of pollutants emitted from the kerosene heaters in the tent. The temporal changes in the aerosol or gas concentration, C_i, can be described by the following equation (Cheng *et al.*, 1995):

$$\frac{dC_i}{dt} = G - (\lambda_v + \lambda_w)C_i, \tag{3}$$

where G is the generation rate in $\mu g\ m^{-3}\ min^{-1}$ for aerosols and in ppm min^{-1} for gases, and λ_w is the wall loss rate in min^{-1}. G was determined by modeling the aerosol or gas profiles with time. According to different concentration profiles of aerosols and gases, various types of the time-dependent generation rates were used. For particles and the CO gas, the concentrations were highest right after the heaters were ignited, then fell very quickly (Figs. 11, 15). The generation rate was chosen with following equation:

$$G = a + b \cdot t \cdot exp(-c \cdot t). \tag{4}$$

For NO and SO_2 gases, the concentration increased as the temperature increased (Figs. 12, 13), so the following equation for the generation rate was used:

$$G = a(1 - exp(-b \cdot t)). \tag{5}$$

Thus, equation 3 can be solved with the initial condition of $t = 0$ and $C_i = 0$, leading to the analytical solution for the particles and CO gas:

$$C_i = \frac{a}{\lambda} + \frac{b}{(\lambda - c)^2}[(\lambda - c)t - 1]\,exp(-ct) + [\frac{b}{(\lambda - c)^2} - \frac{a}{\lambda}]\,exp(-\lambda t), \tag{6}$$

and for NO and SO_2 gases:

$$C_i = \frac{a}{\lambda} - \frac{a}{\lambda - b}exp(-b \cdot t) + (\frac{a}{\lambda - b} - \frac{a}{\lambda})exp(-\lambda t), \tag{7}$$

where $\lambda = \lambda_v + \lambda_w$.

The constants a, b, and c can be calculated by fitting equations 6 and 7 into the experimental data. Thus, the equations for the emission rate of particles and gases from various heaters and fuels can be obtained.

Wall Loss Rate

The air exchange rate and wall loss rate should be obtained while solving equations 6 and 7. The air exchange rate can be calculated with equation 1 as discussed previously.

Crump and Seinfeld (1981) gave an equation to calculate the wall loss rate for vessels of arbitrary shape. After simplifying the equation to the specific tent, the wall loss rate (λ_w) can be determined by:

$$\lambda_w = \frac{1}{V}\left[\frac{2\sqrt{k_e \cdot D} \cdot A_s}{\pi} - \frac{U_t \cdot A_b}{exp(-\frac{\pi \cdot U_t}{2\sqrt{k_e \cdot D}}) - 1} + \frac{U_t \cdot A_t}{exp(\frac{\pi \cdot U_t}{2\sqrt{k_e \cdot D}}) - 1}\right], \tag{8}$$

where V is the volume of the tent; A_s, A_b, and A_t represent the areas of the tent sides, bottom, and top, respectively; U_t and D are the particle settling velocity and the Brownian diffusion coefficient; and k_e is a constant that is related with the volumetric flow rate (Q) through the vessel (Crump *et al.*, 1983).

$$k_e = 0.00918Q^{1.5}, \tag{9}$$

where k_e is given in sec^{-1} if Q is expressed in l/min. Figure 26 shows a comparison of the wall loss rates, when the air exchange rate ranged from 1 to 3.6 h^{-1} (the experimental conditions). Figure 26 indicates that the loss from the walls is much smaller than that from ventilation when the particle size was below 2.5 μm.

Generation Rates and Emission Factors

In the experiments, non-linear regressions for particle and NO concentrations were available in all cases. However, some gas profiles (e.g., SO_2, CO) were still not available because of their low concentrations. Over 50 curve regressions with a commercial software, TableCurve (SPSS Inc., Chicago, IL), were carried out to obtain the generation rate. Figures 27 - 29 show the typical examples of the regression results for gas (CO, NO, and SO_2) concentrations, and Figure 30 gives the regression result for the particle concentration. After averaging all results for the same heater and fuel, the generation rate of a specific gas or particle can be determined. By integrating the generation rate, *G*, the total gas or particle generation concentration in the time *t* can be calculated.

Our data show that CO and PM generation rates rose rapidly after ingition, reached maximum at about 10 min post ignition, then declined rapidly. In contrast, the SO_2 and NO generation rate rose and stayed at a constant level for the entire combustion period. Based on the data of the fuels and heaters (Table 1) and the volume of the tent (106 m^3), the emission factor (μg/kJ) for a specific pollutant can be obtained. Table 3 shows the equations for the generation rate and emission factors for all pollutants in various types of heaters and fuels. The convection heaters emitted more NO and SO_2 gases, but less CO gas and fewer particles than the radiant heater. The emission factors based on heaters were also compared to studies in which kerosene fuel was burned (Traynor *et al.*, 1983, 1990; Apte and Traynor, 1986) (Table 4). These studies also showed the low CO and high NO emission factors for convection heaters, the same trend as in our study. The emission factors for these gases and particles are similar in order of magnitude.

DOSE CALCULATION RESULTS

Table 5 gives the deposition fractions during sleep and rest with 100% nose breathing and the 100% mouth breathing. Thus, the dose in different regions of the lung, including total particles and specific particle size, can be calculated with the particle distribution measured by the MOUDI, the particle generation rate (Table 3), and the particle deposition fractions in the lung (Table 5).

The particle deposition fractions in different parts of the human lung for specific particle sizes (classified by the MOUDI) during sleep and rest were calculated by the NCRP computer model. With the results of particle distribution and generation rate (Tables 3 and 5), the number of particles deposited in the lung for a specific particle size can be obtained. Thus, the total and regional doses in the lung can be determined. Table 6 shows the total particle deposition in different parts of the human lung for various heaters and fuels. The deposition dose for a specific particle size is listed in Appendix III. The results indicate that the largest number of particles were deposited when the AWHR heater burned 1-K fuel (0.968 mg), and the smallest (0.307 mg) was when an RMC heater burned JP-8 fuel. All other cases ranged between 0.57 – 0.81 mg. The depositions for normal augmenters were slightly larger than those of mouth breathers. Because the heaters emitted fine particles, the amount of particles deposited in the P region was as high as, sometimes even higher than, that in the NOPL region.

RESEARCH ACCOMPLISHMENTS

- Simulated exposure to unvented heater exhaust in an Army tent.
- Measured levels of CO, NO, SO_2 and particulate concentrations in the tent as a function of air exchange rate.
- Measured the particle size distribution, indicating which particles were ultrafine
- Determined the detailed chemical composition of particulate matter
- Determined the emission factors of measured pollutants as a function of heater and fuel types.
- Estimated dose of inhaled particles from portable heater exhaust

REPORTABLE OUTCOMES

Presentations:

1. Cheng, Y.S., Zhou, Y., and Francis, J. Characterization of Emissions in an Army Tent from Unvented Kerosene Heaters, The American Association for Aerosol Research'98, June 22-26, 1998, Cincinnati, Ohio.
2. Zhou, Y., Cheng, Y.S., and Francis, J. Characterization of Emissions in an Army Tent from Unvented Kerosene Heaters, 5th International Aerosol Conference, September 14-18, 1998, Edinburg, UK.

Publications:

1. Zhou, Y., Cheng, Y.S., and Francis, J. (1998). Characterization of Emissions in an Army Tent from Unvented Kerosene Heaters, *J. Aerosol Sci.* 29(S): 285 - 286.
2. Zhou, Y. and Cheng, Y.S. (in press) Characterization of Emissions from Kerosene Heaters in an Unvented Tent, *Aerosol Sci. & Technol.*
3. Cheng, Y.S., Zhou, Y., Chow, J.C., Watson, J.G., and Frazier, C.A. (in preparation), Chemical Composition Analysis of Aerosols from Kerosene Heaters, *Aerosol Sci. & Technol.*

CONCLUSIONS

Our experimental data indicate high concentrations of PM, NO_X, CO, and SO_2 inside the Army tent. The PM data are higher than the current limits of the NAAQS when the tent doors were closed. We found that the air exchange rate was a major factor in determining pollutant concentration in the tent. Both gas and PM concentrations decreased as the air exchange rate increased. Concentrations of gases and PM also varied depending on types of the fuel and heater. From these data, we see that the AWHR-1101 heater emitted higher particle and CO concentrations than the other two kinds of heaters, even though the AWHR-1101 is less powerful (10,000 Btu/h) than the others (22,000 Btu/h). The 1-K kerosene showed the highest particle concentrations among the three kinds of fuels, whereas the JP-8 showed the lowest. It is difficult to determine the CO concentration of the different fuels. JA-1 showed good emission results when burned by RMC and Omni heaters; however, JA-1 also showed the poorest result when burned in the AWHR heater. There was no significant difference among the fuels in the NO concentration. The NO concentrations from the RMC and Omni heaters were much larger than those from the AWHR heater. The RMC heater emitted almost no SO_2, but an average of 1.41 ppm of the NO concentration for the three fuels. However, the Omni heater showed a high concentration of SO_2 (1.01 ppm in average). Lastly, the particle and gas concentrations decreased with the increasing air exchange rate.

The elemental analysis results indicate high concentrations of sulfur, EC, OC, $SO_4^{=}$, and NH_4^+ in combustion aerosols produced from the kerosene heaters. These data indicate that the AWHR-1101 heater produced more emissions for the EC and OC concentrations than the other two kinds of heaters, even though the AWHR-1101 is less powerful than the others. This result agreed with our study of CO concentrations. The same result was also obtained for the sulfur concentration with elemental analysis. The RMC heater emitted the lowest $SO_4^{=}$ concentration compared to other heaters, which also agrees with the results of SO_2 gas concentration measured previously. The 1-K kerosene showed the highest sulfur concentration among the three kinds of fuels, whereas the JA-1 showed the lowest. The 1-K also showed the highest NH_4^+ concentration in the IC analysis. The NO_3^- concentration was low in all cases

(<0.25 μg/m^3); many of the NO_3^- concentrations were below the detection limit. The average carbon, $SO_4^=$, and NH_4^+ concentration ratios for PM-2.5 and PM-10 were around 1.0. These results are consistent with particle size distribution and indicate that the aerosols were smaller than 2.5 μm.

Simulation of air pollutant concentration using a indoor air model provides us with generation rate for both particulate and gases. This simulation shows that both CO and particulates were generated in a short pulse at the beginning of combustion when the combustion temperature was low. SO_2 and NO reached a stable generation soon after the combustion temperature was stabilized. The generation rates and the emission factors of the pollutants were calculated from the experimental data. The results showed higher levels of NO and SO_2 and a lower level of CO and particles for the convection heaters, thus confirming the results reported in the literature. For a specific heater and fuel, the particle dose was determined with the particle distribution, the particle deposition fraction in human lungs, and the particle generation rate. Our results showed a high particle dose from all heaters and fuels. The dose from the RMC heater and the JP-8 fuel showed a relatively low value, about 50% lower than the average. The doses in the P region were as high as those in the NOPL region on the average. The dose results indicate that the U.S. military personnel inhaled many particles from unvented heaters during the Persian Gulf War.

REFERENCES

ACGIH (1998). *TLVs and BEIs, Threshold Limit Values for Chemical Substances and Physical Agents*, Cincinnati, OH.

Apte, M.G. and Traynor, G.W. (1986). Comparison of pollutant emission rates from unvented kerosene and gas space heaters, *Proceedings, IAQ '86 Managing Indoor Air for Health and Energy Conservation*, ASHRAE, Atlanta, GA, 405 - 416.

Centers for Disease Control and Prevention (CDC) Report (1999). *Background Document on Gulf War-Related Research for the Health Impact of Chemical Exposures During the Gulf War: A Research Planning Conference,* CDC.

Cheng, Y.S., Bechtold, W.E., Yu, C.C., and Hung, I.F. (1995). Incense smoke: Characterization and dynamics in indoor environments, *Aerosol Sci. Technol.* 23:271-

281.

Crump, J.G. and Seinfeld, J.H. (1981). Turbulent deposition and gravitational sedimentation of an aerosol in a vessel of arbitrary shape, *J. Aerosol Sci.* 12:405-415.

Crump, J.G., Flagan, R.C., and Seinfeld, J.H. (1983). Particle wall loss rates in vessels, *Aerosol Sci. Technol.* 2:303-309.

Dzubay, T.G. and Stevens, R.K. (1975). Ambient air analysis with dichotomous sampler and X-ray fluorescence spectrometer. *Environ. Sci. Technol.* 9:663-667.

Huntzicker, J.J., Johnson, R.L., Shah, J.J., and Cary, R.A. (1982). Analisis of Organic and Elemental Carbon in Ambient Aerosol by a Thermal-Optical Method. In *Particulate Carbon: Atmospheric Life Cycle* (edited by: Wolff, G.T. and Klimisch, R.L.), pp 79-88, Plenum Press, New York.

Institute of Medicine (IOM) Report (1995). *Health Consequences of Service During the Persian Gulf War: Initial Findings and Recommendations for Immediate Action,* National Academy Press, Washington, DC.

Jaklevic, J.M., Loo, B.W., and Goulding, F.S. (1977). Phoyon-Induced X-Ray Fluorescence Analysis Using Energy-Dispersive Detection and Dichotomous Sampler. In *Induced X-Ray Fluorescence Analysis of Environmental Samples,* 2nd ed. (edited by: Dzubay, T.G.), pp 3-18, Ann Arbor, MI: Ann Arbor Science.

Leaderer, B.P., and Boone, P.M. (1990). Total particle, sulfate, and acidic aerosol emissions from kerosene space heaters, *Environ. Sci. Technol.* 24:908-912.

Mueller, P.K., Mendoza, B.V., Collins, J.C. and Wilgus, E.S. (1978). Application of Ion Chromatography to the Analysis of Anions Extracted from Airborne Particulate Matter. In *Chromatographic Analysis of Environmental Pollutants* (edited by: Sawicki, E., Mulik, J.D., and Wittgenstein, E.), pp 77-86, Ann Arbor, MI: Ann Arbor Science.

Mumford, J.L., Lewtas, J., Williams, K., Tucker, W.G., and Traynor, G.W. (1992). Mutagenicity of organic emissions from unvented kerosene heaters in a chamber study, *J. Toxicol. Environ. Health.* 36:151-159.

NCRP (1997). *Deposition, Retention and Dosimetry of Inhaled Radioactive Substances*, Report No. 125. National Council on Radiation Protection and Measurements, Bethesda, MD.

Relwani, S.M., and Moschandreas, D.J. (1986). Effects of operational factors on pollutant emission rates from residential gas appliances, *JAPCA.* 36:1233-1237.

Setiani, O. (1994). Indoor air quality and ventilation strategies in the use of combustion space heating appliances in housing, *Hiroshima. J. Med. Sci.* 43:163-167.

Small, H., Stevens, T.S., and Bauman, W.C. (1975). Novel ion exchange chromatographic method using conductimetric detection, *Anal. Chem.* 47:1801-1809.

Small, H. (1978). An Introduction to Ion Chromatography. In *Chromatographic Analysis of Environmental Pollutants* (edited by: Sawicki, E., Mulik, J.D., and Wittgenstein, E.), pp 11-22, Ann Arbor, MI: Ann Arbor Science.

Traynor, G.W., Allen, J.R., Apte, M.G., Girman, J.R., and Hollowell, C.D. (1983). Pollutant emissions from portable kerosene-fired space heaters, *Environ. Sci. Technol.* 17:369 - 371.

Traynor, G.W., Girman, J.R., Apte, M.G., and Dillworth, J.F. (1985). Indoor air pollution due to emissions from unvented gas-fired space heaters, *JAPCA.* 35:231-237.

Traynor, G.W., Apte, M.G., Sokol, H.A., Chuang, J.C., Tucker, W.G., and Mumford, J.L. (1990). Selected organic pollutant emissions from unvented kerosene space heaters, *Environ. Sci. Technol.* 24:1265-1270.

Tu, K.W., and Hinchliffe, L.E. (1983). A study of particulate emissions from portable space heaters, *Am. Ind. Hyg. Assoc. J.* 44:857-862.

U.S. Environmental Protection Agency (1994a). Methods for Determination of Metals in Environmental Samples, Supplement I, EPA/600/R-94/111, May.

U.S. Environmental Protection Agency (1994b). National Ambient Air Quality Standards for Carbon Monoxide: Final Decision, *Federal Register* Vol. 59, No 148, August 1.

U.S. Environmental Protection Agency (1996a). *Air Quality Criteria for Particulate Matter,* Volume I of III, EPA/600/P-95/001aF, p. 7-58, April.

U.S. Environmental Protection Agency (1996b). National Ambient Air Quality Standards for Sulfur Oxides (Sulfur Dioxide): Final Decision, *Federal Register* Vol. 61, No 100, May 22.

U.S. Environmental Protection Agency (1997). National Ambient Air Quality Standards for Particulate Matter: Final Rule, *Federal Register* Vol. 62, No 138, July 18.

Watson, J.G., Chow, J.C., and Frazier, C.A. (1996). X-Ray Fluorescence Analysis of Ambient Air Samples, In *Elemental Analysis of Airborne Particles* (edited by: Landsberger, S. and Creatchamn, M.), pp 67–96, Gordon and Breach Publishers, U.S.A.

PERSONNEL PAID FROM THE RESEARCH EFFORT

Yung-Sung Cheng, Lovelace Respiratory Research Institute

Yue Zhou, Lovelace Respiratory Research Institute

Thomas D. Holmes, Lovelace Respiratory Research Institute

Jonathan Francis, Lovelace Respiratory Research Institute

Judith C. Chow, Desert Research Institute

Clifton A. Frazier, Desert Research Institute

John G. Watson, Desert Research Institute

APPENDICES

APPENDIX I. FIGURES AND TABLES CITED IN BODY OF REPORT

APPENDIX II. OVERALL RESULTS OF THE EXPERIMENTS

APPENDIX III. DOSE FOR SPECIFIC PARTICLE SIZE

APPENDIX I. FIGURES AND TABLE CITED IN BODY OF REPORT

LIST OF FIGURES

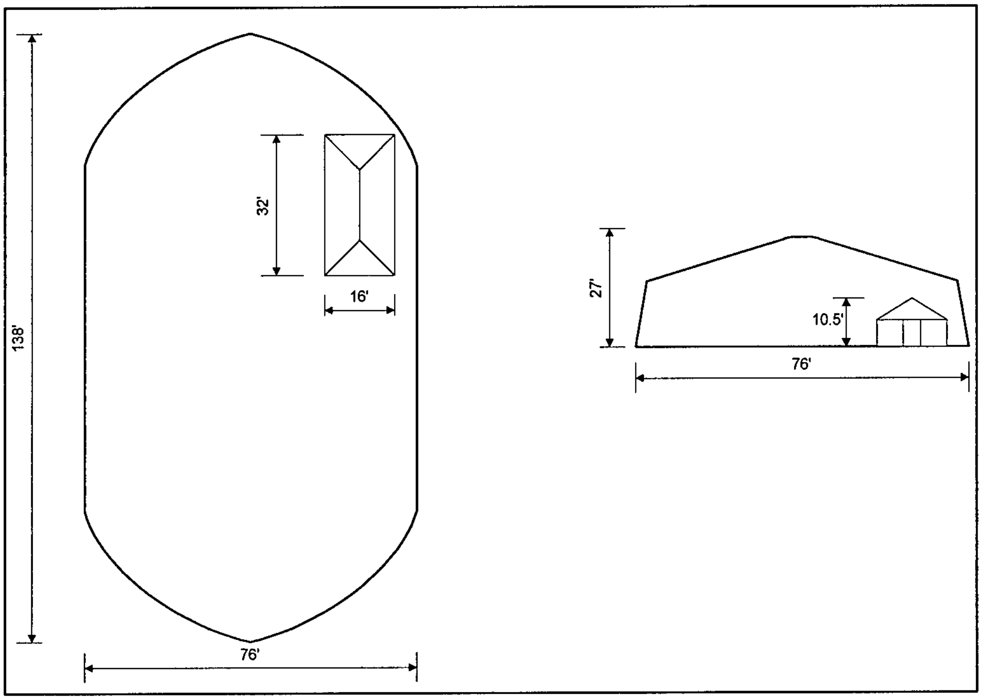


Fig. 1. Schematic of the Army tent inside the clamshell.

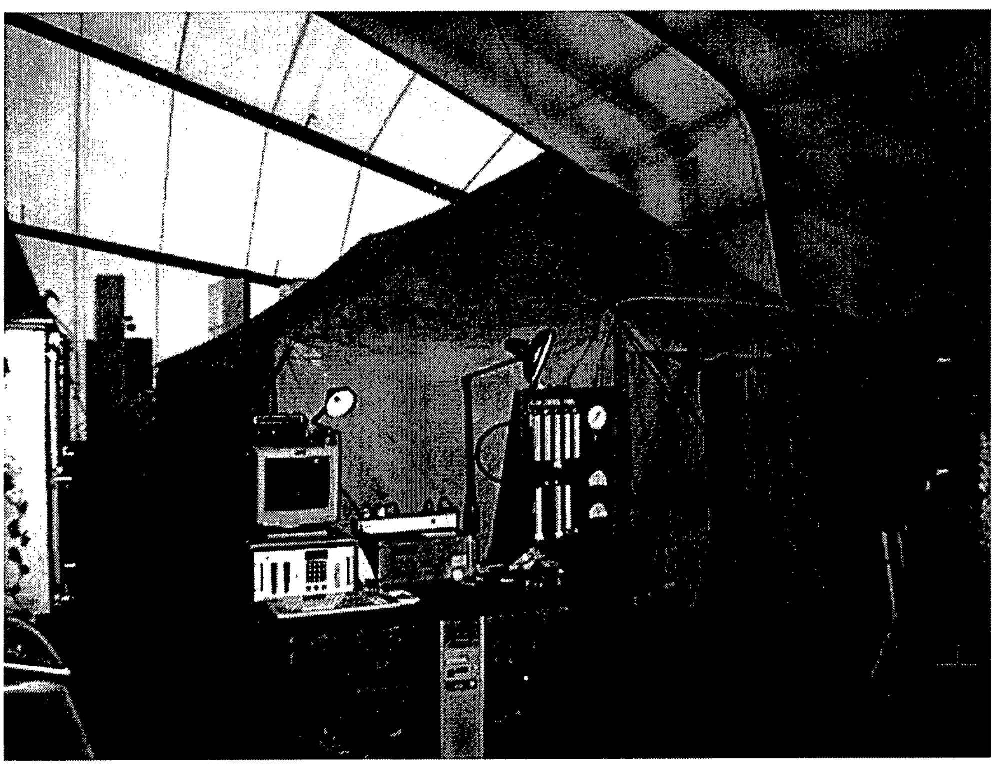


Fig. 2. The Army tent and the instrument control panel inside the clamshell.

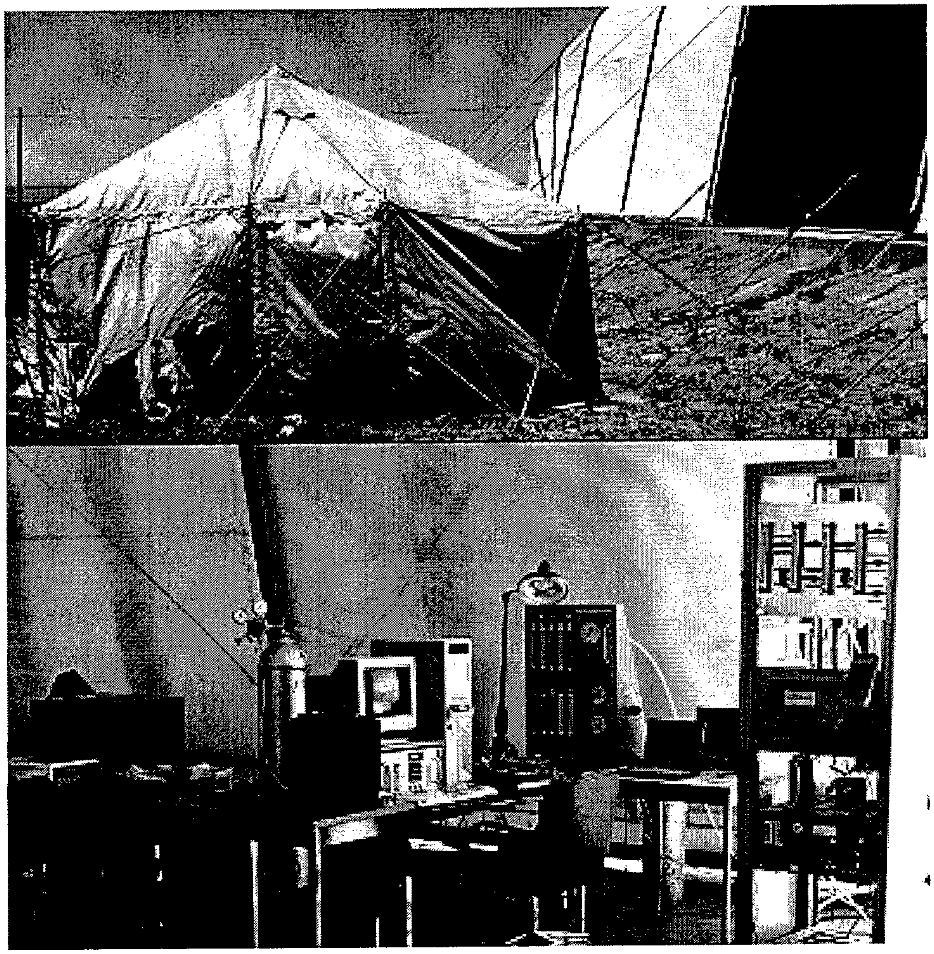


Fig. 3. Army tent outdoors and the instrument control panel inside the clamshell.

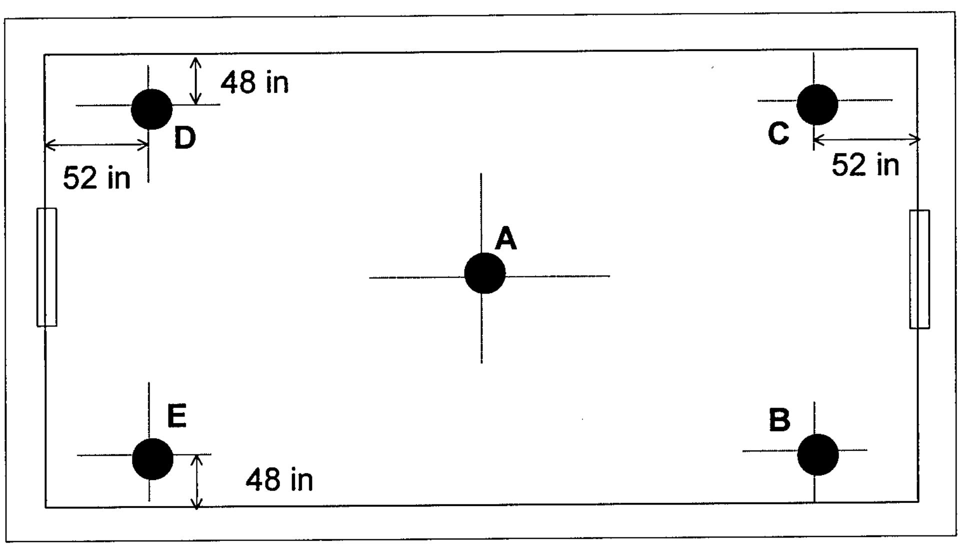


Fig. 4. The position of Personal Environmental Monitors for the pre-test.

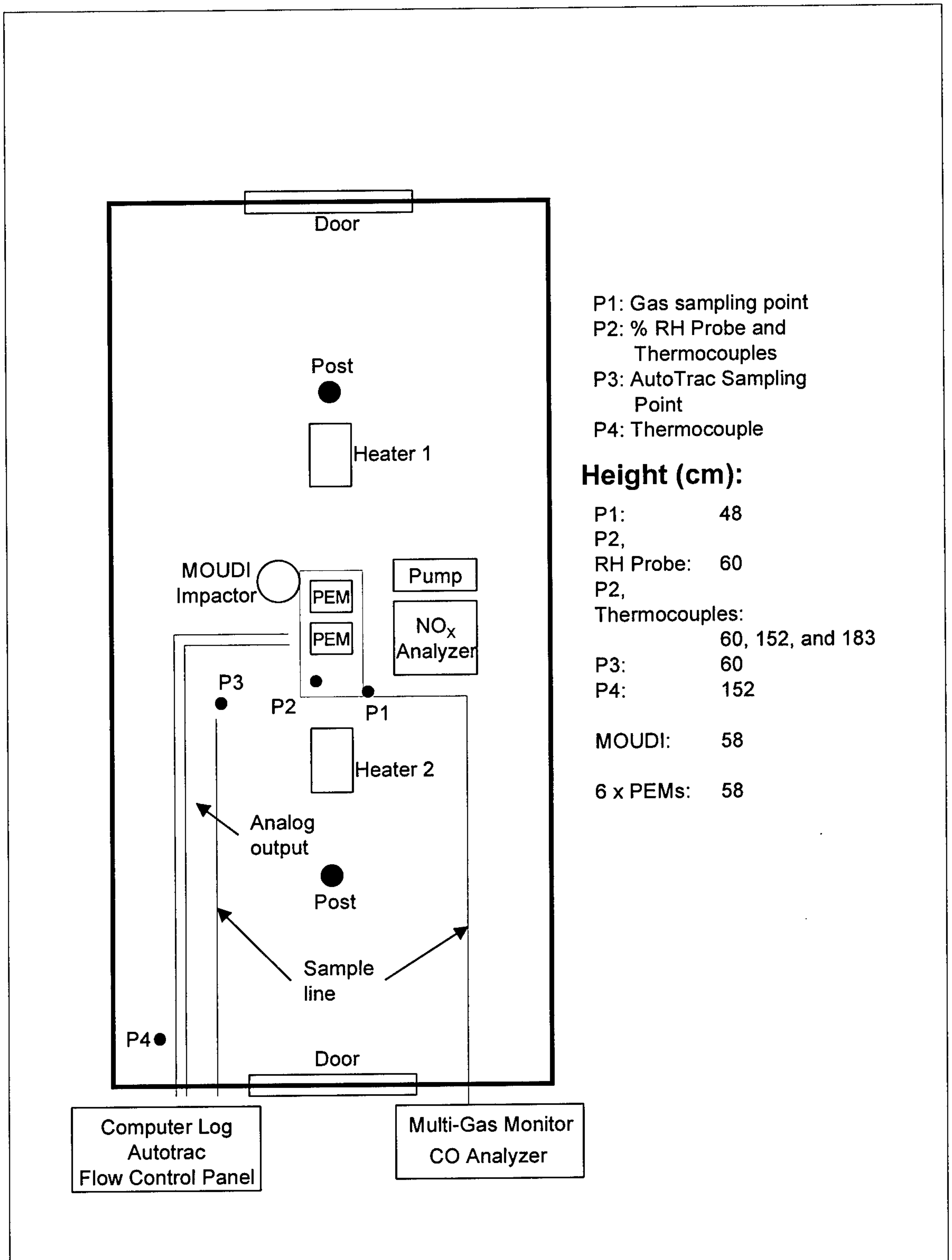


Fig. 5. Schematic of the experimental set-up, including the positions of the sampling instruments within the tent. MOUDI = Micro-Orifice Uniform Deposit Impactor. RH = Relative Humidity. PEM = Personal Environmental Monitor; three PM-2.5 PEMs and three PM-10 PEMs.

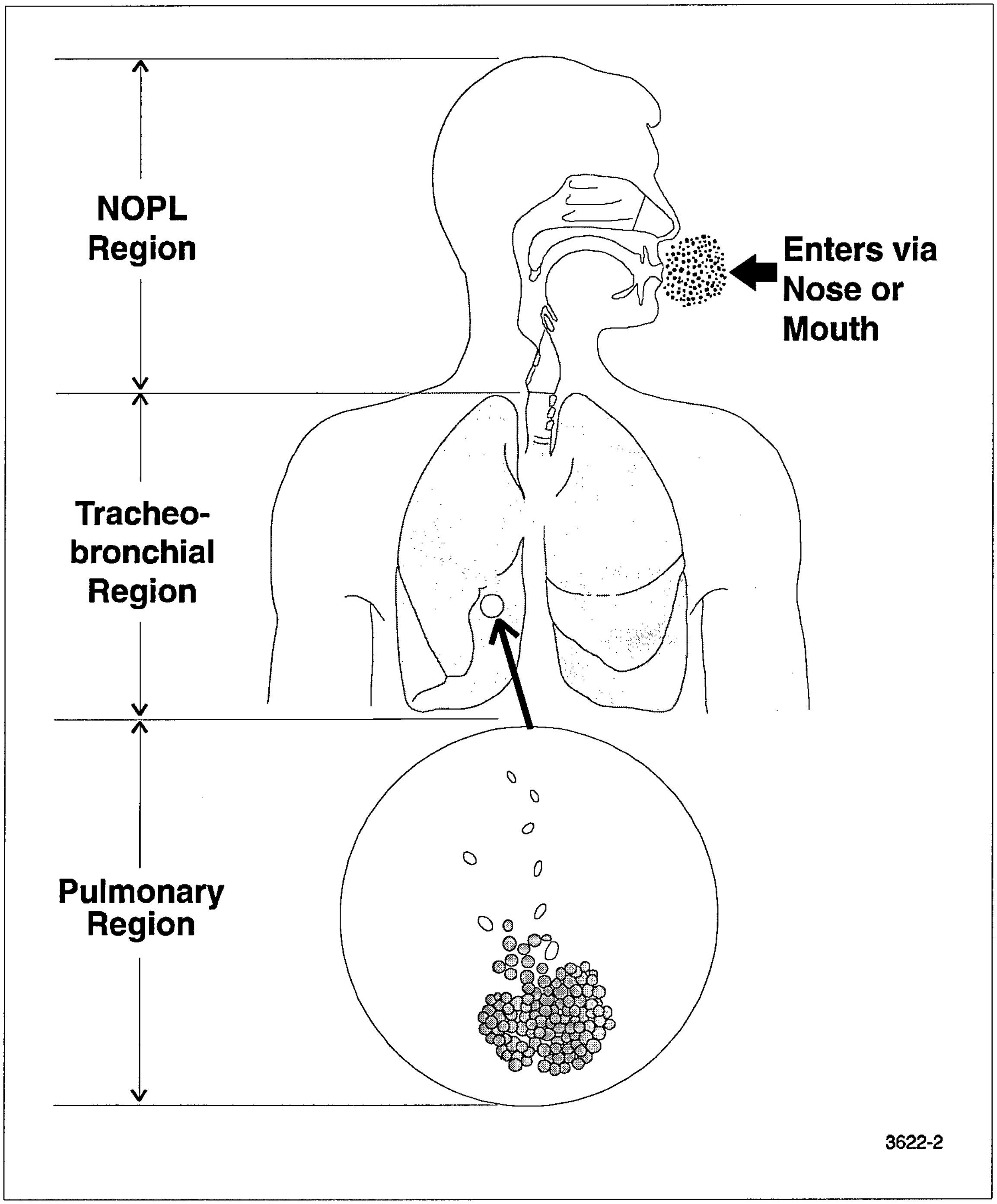


Fig. 6. Anatomical regions of respiratory tract. NOPL = Naso-Oro-Pharyngolaryngeal.

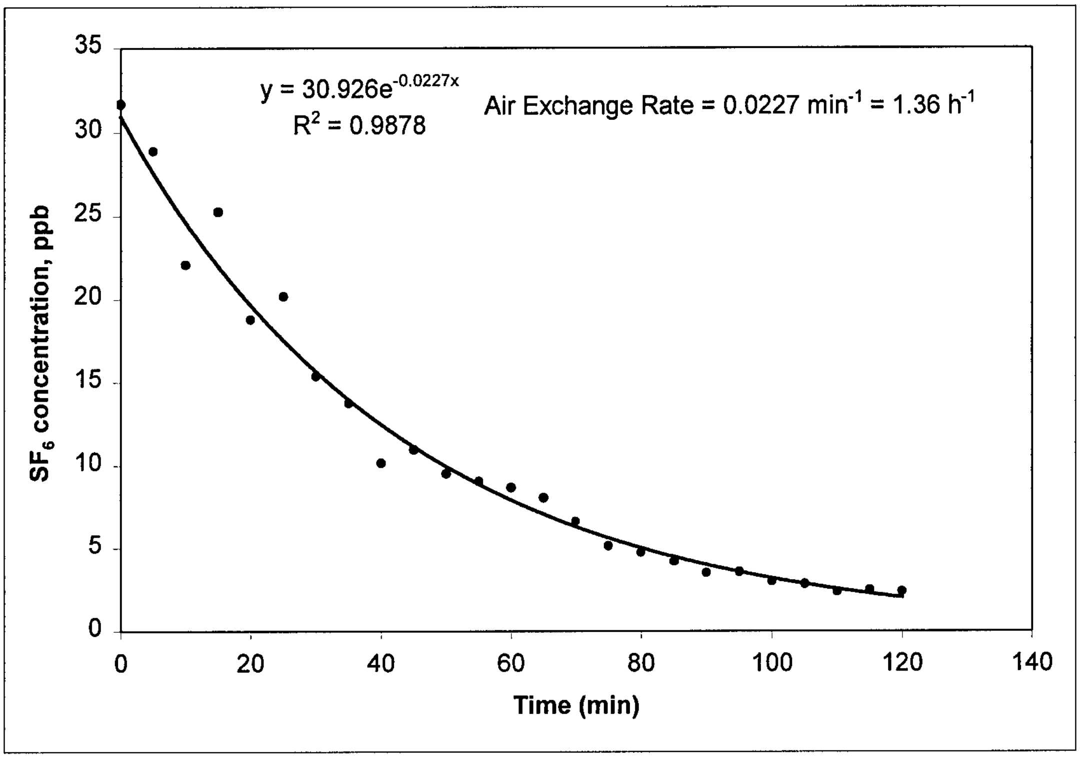


Fig. 7. SF_6 concentration decay as a function of time.

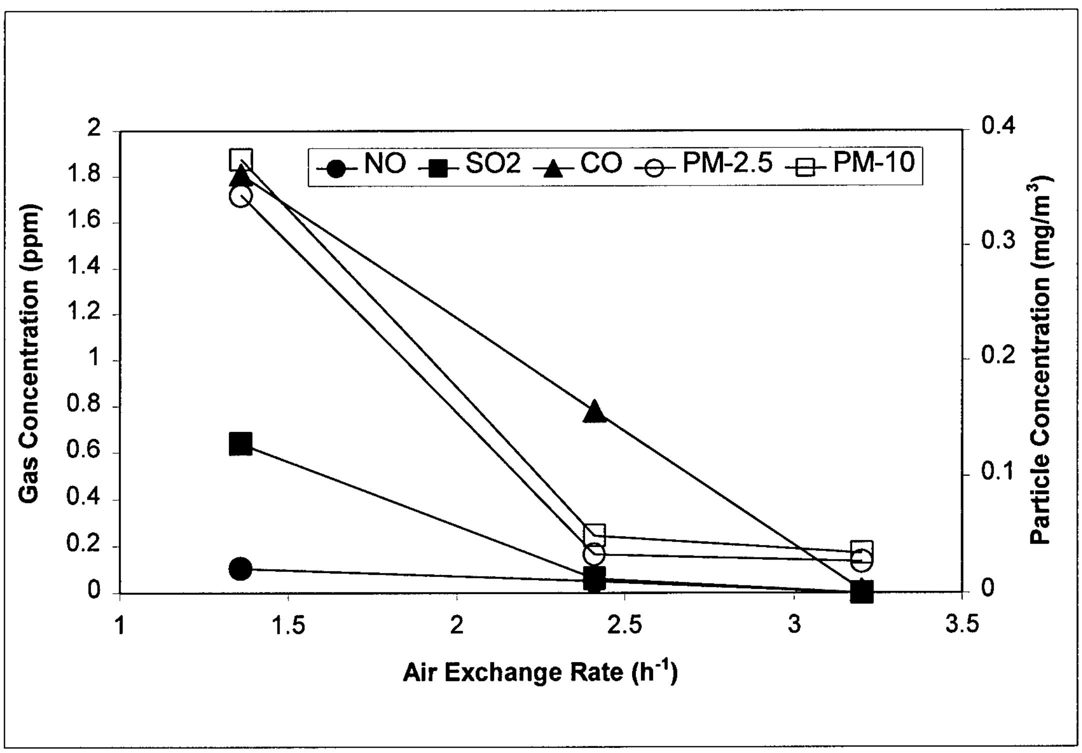


Fig. 8. Particle and gas concentrations in the tent as a function of the air exchange rate. Two AWHR heaters and JA-1 fuel were used in the experiment.

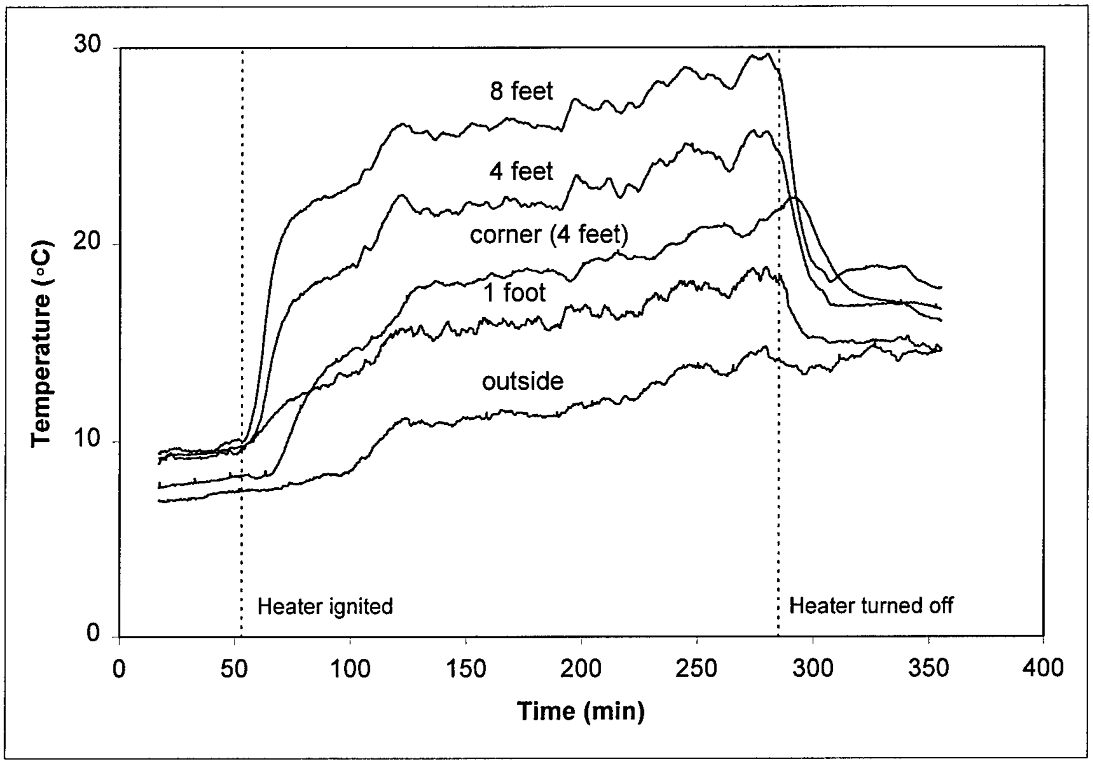


Fig. 9. Temperature profiles in various locations when two AWHR heaters and JA-1 fuel were used in the experiment. The air exchange rate was 1.36 h^{-1}.

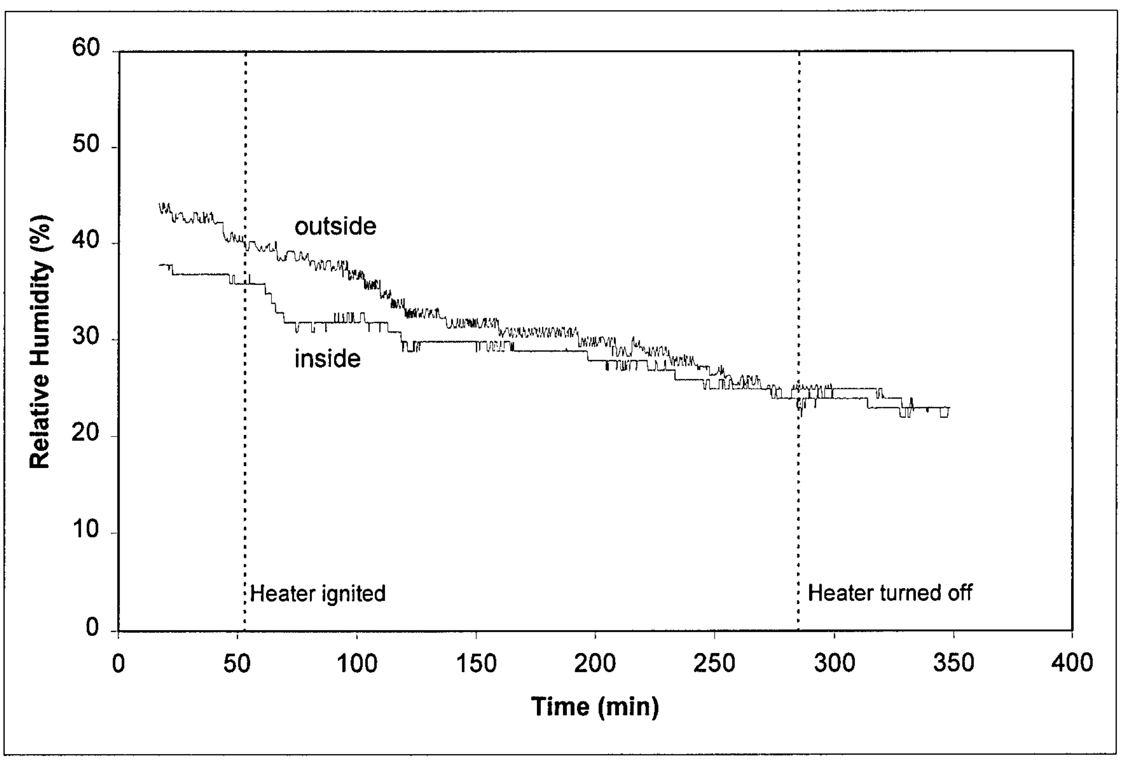


Fig. 10. Relative humidity profiles in various locations when two AWHR heaters and JA-1 fuel were used in the experiment. The air exchange rate was 1.36 h^{-1}.

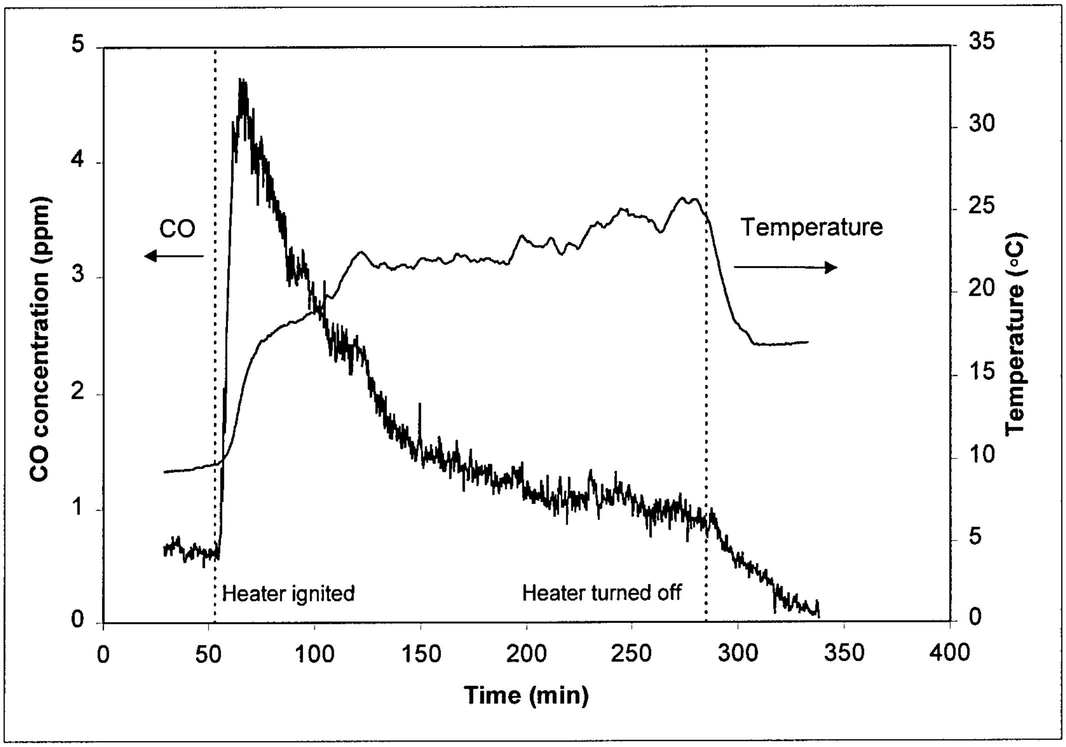


Fig. 11. CO concentration and temperature profiles when two AWHR heaters and JA-1 fuel were used. The tent doors were closed; the air exchange rate was 1.36/h.

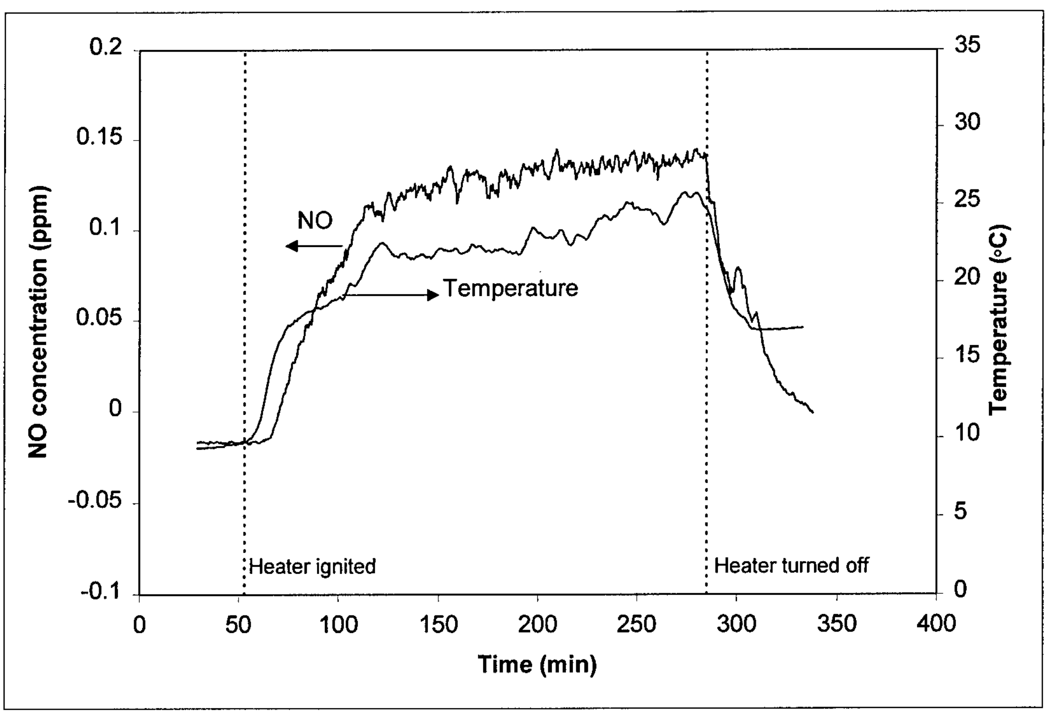


Fig. 12. NO concentration and the temperature profiles during a test with two AWHR heaters and JA-1 fuel. The air exchange rate was 1.36 h^{-1}.

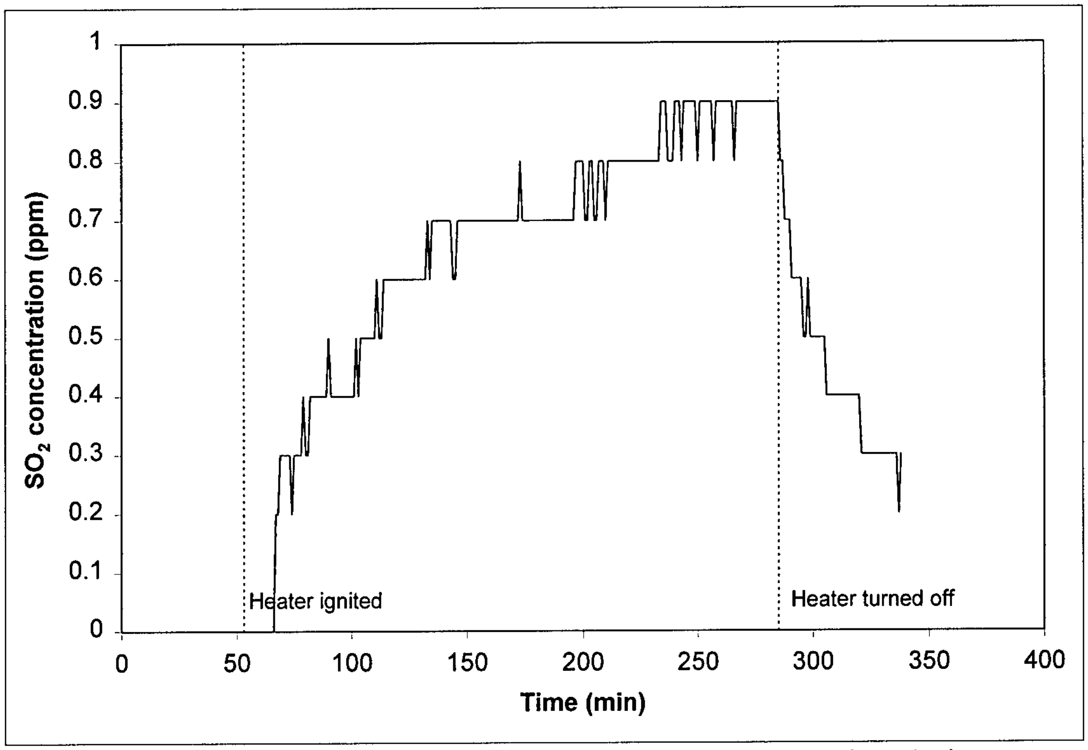


Fig. 13. SO_2 concentration profile measured by the Multi-Gas Monitor during a test with two AWHR heaters and JA-1 fuel. The air exchange rate was 1.36 h^{-1}.

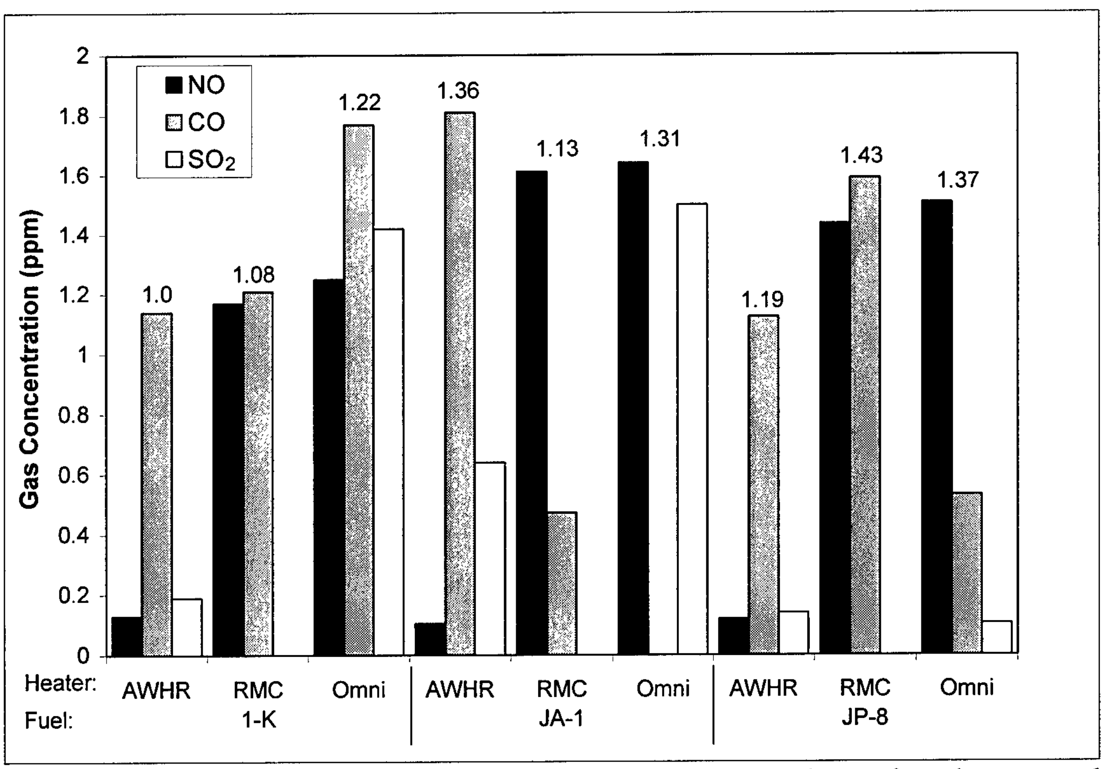


Fig. 14. Comparison of the gas concentrations (average value) for various heaters and fuels. The air exchange rate, the number above each bar, ranged from 1.0 to 1.43 h^{-1}.

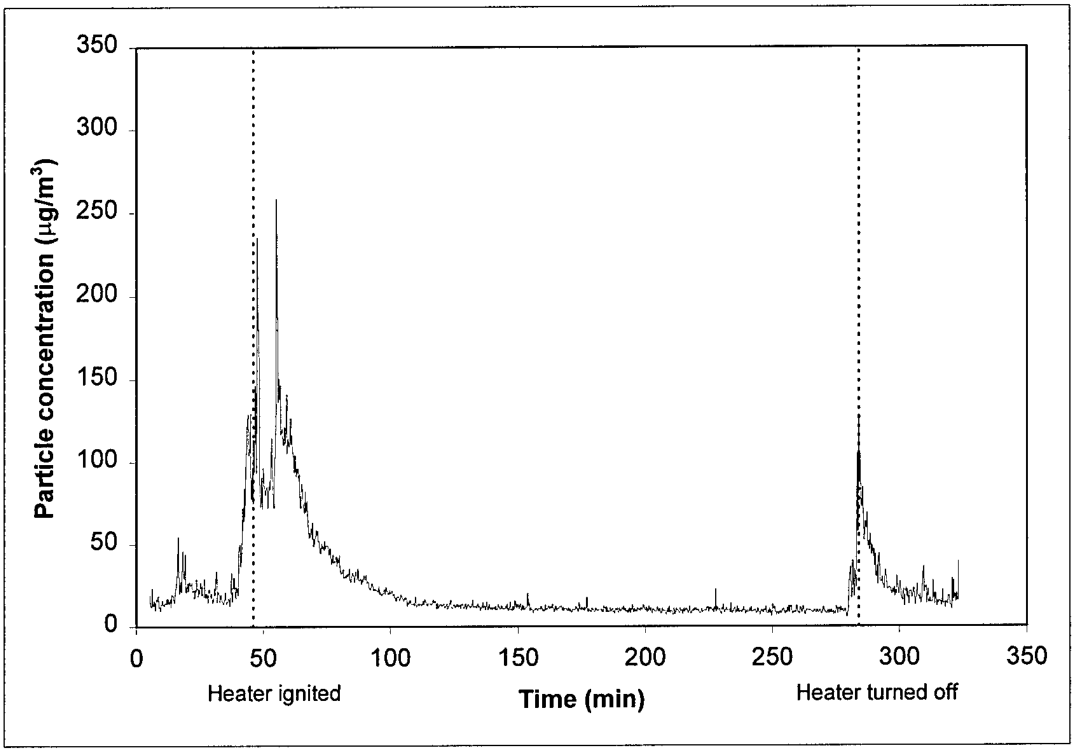
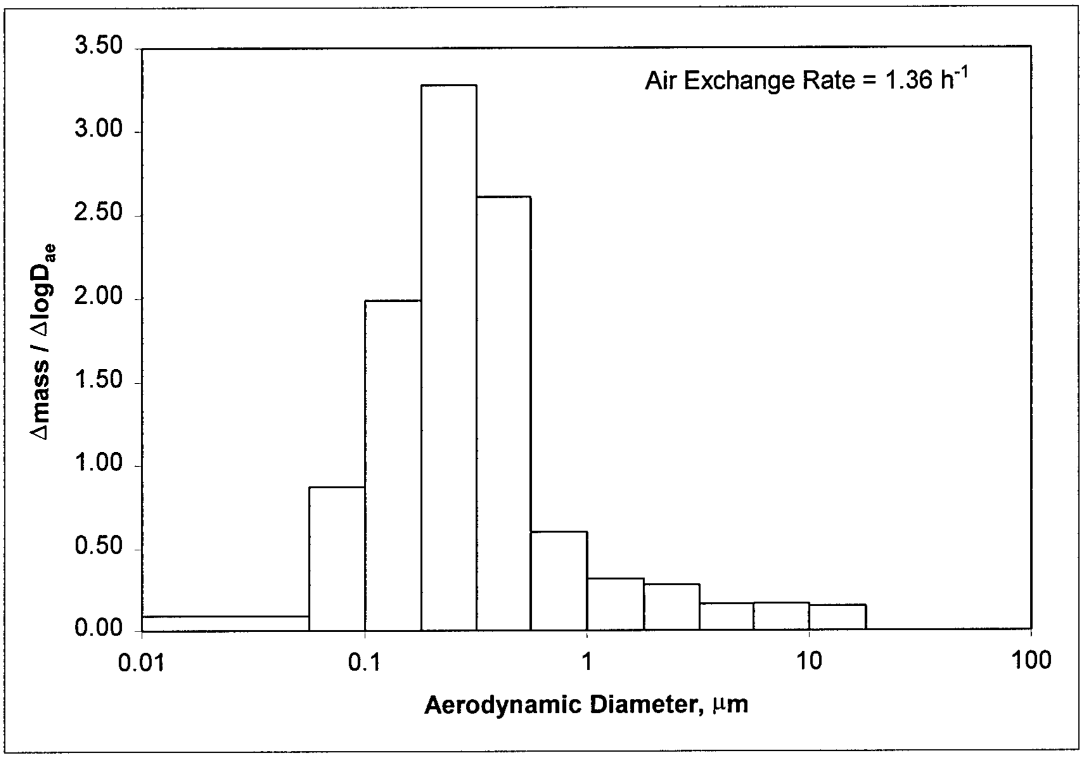


Fig. 15. The real-time particle mass concentration measured by the DataRAM monitor. Two AWHR heaters and JA-1 fuel were used; the air exchange rate was 2.41 h^{-1}.



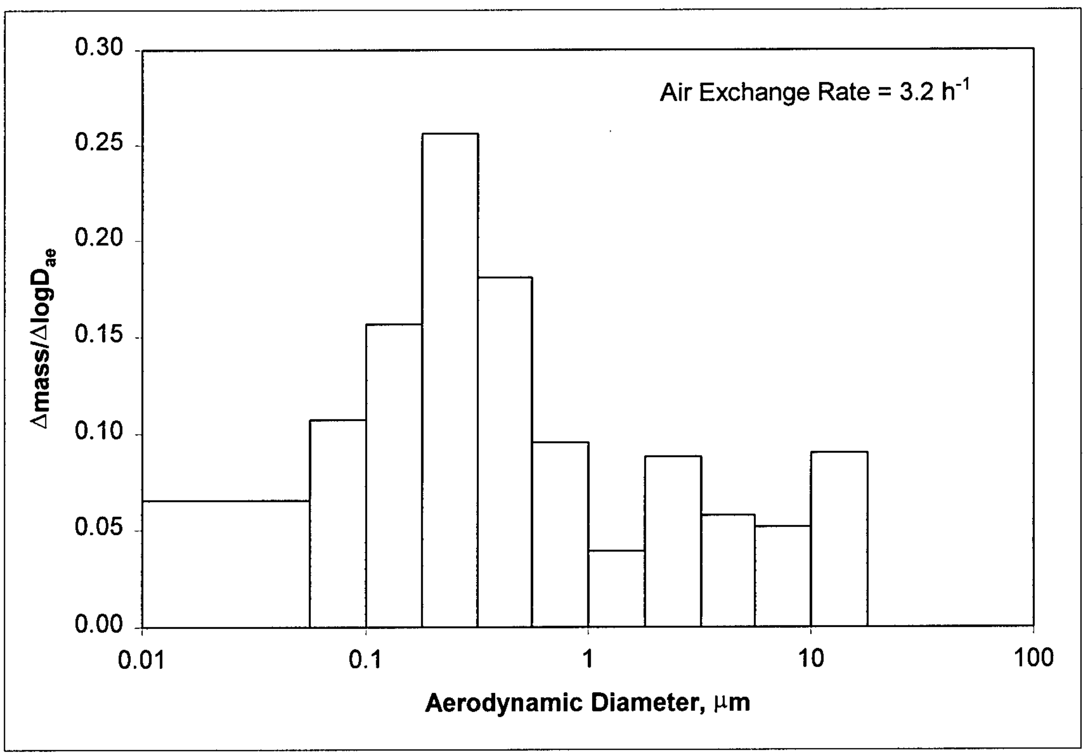


Fig. 16. The particle size distributions (mass) obtained by a MOUDI impactor. Two AWHR heaters and JA-1 fuel were used in the test; the air exchange rates were 1.36 and 3.2 h^{-1}.

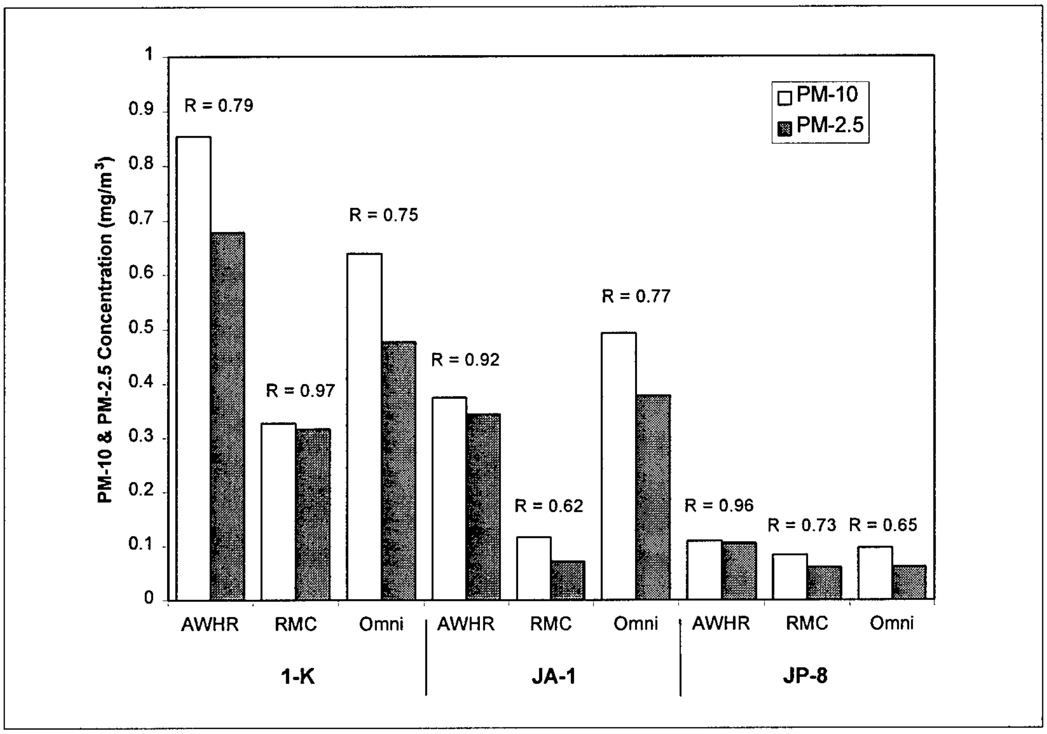


Fig. 17. Comparison of PM-10 and PM-2.5 concentrations among various heaters and fuels; the air exchange rate ranged from 1.0 to 1.43 h^{-1}. R is the ratio of PM-2.5 and PM-10.

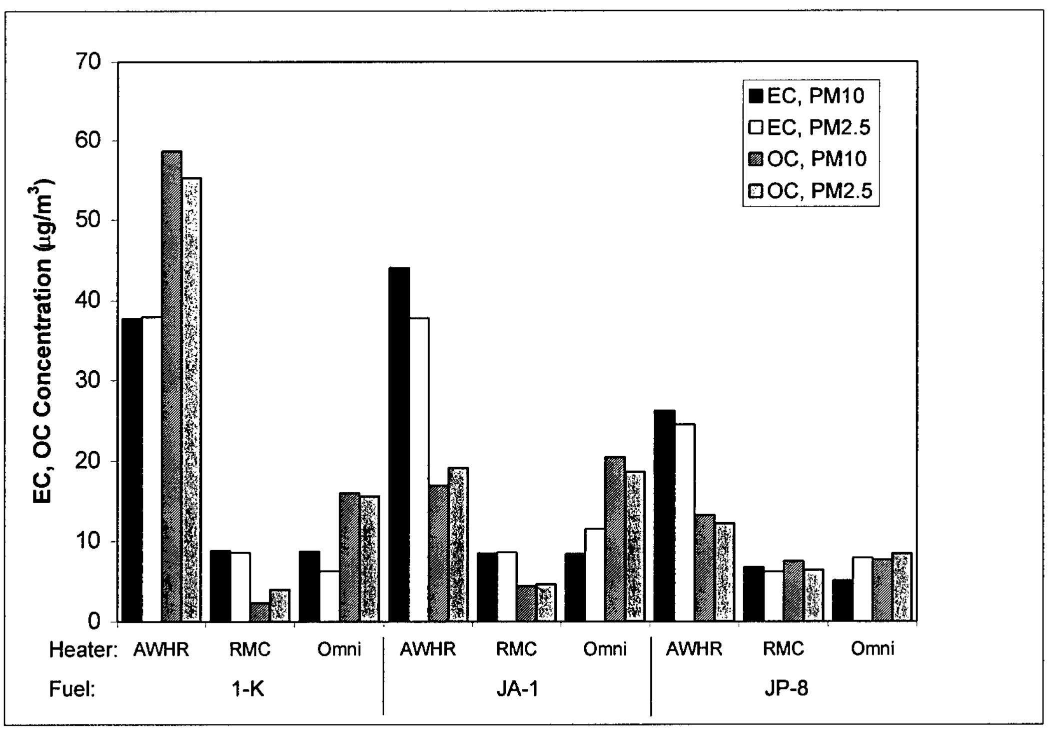


Fig. 18. Comparison of the elemental and organic carbons (EC and OC) for PM-2.5 and PM-10 particles when the tent doors were closed. The air exchange rate ranged from 1.0 to 1.43 h^{-1}.

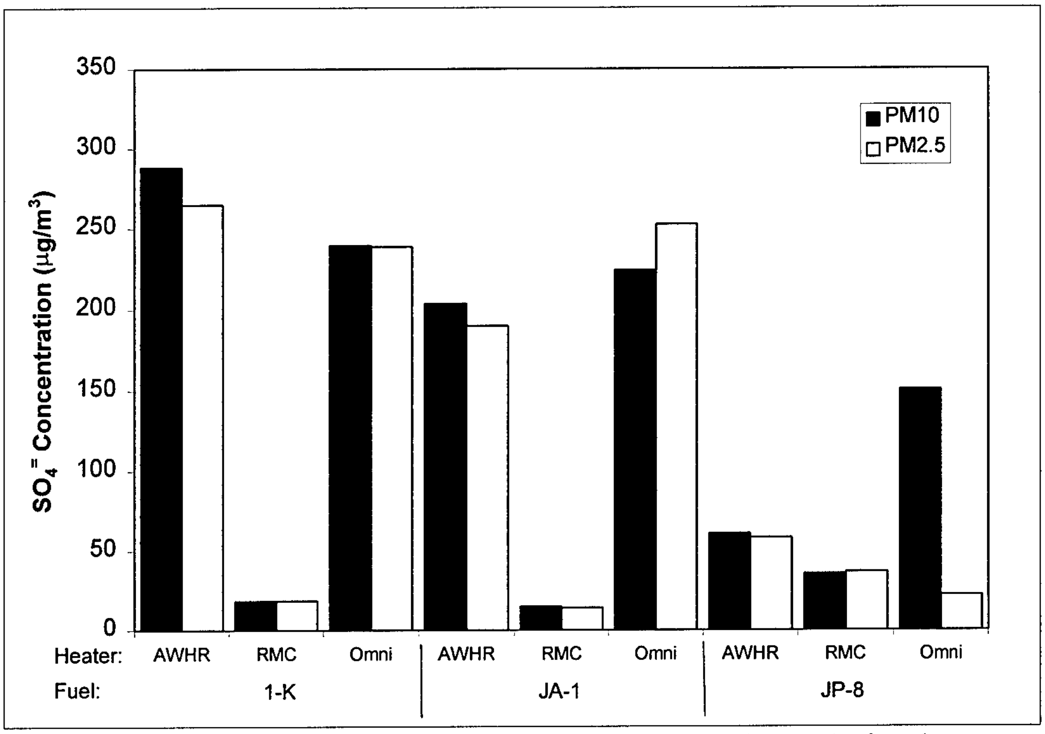


Fig. 19. The $SO_4^{=}$ concentrations from the ion chromatography analysis when tent doors were closed. The air exchange rate ranged from 1.0 to 1.43 h^{-1}.

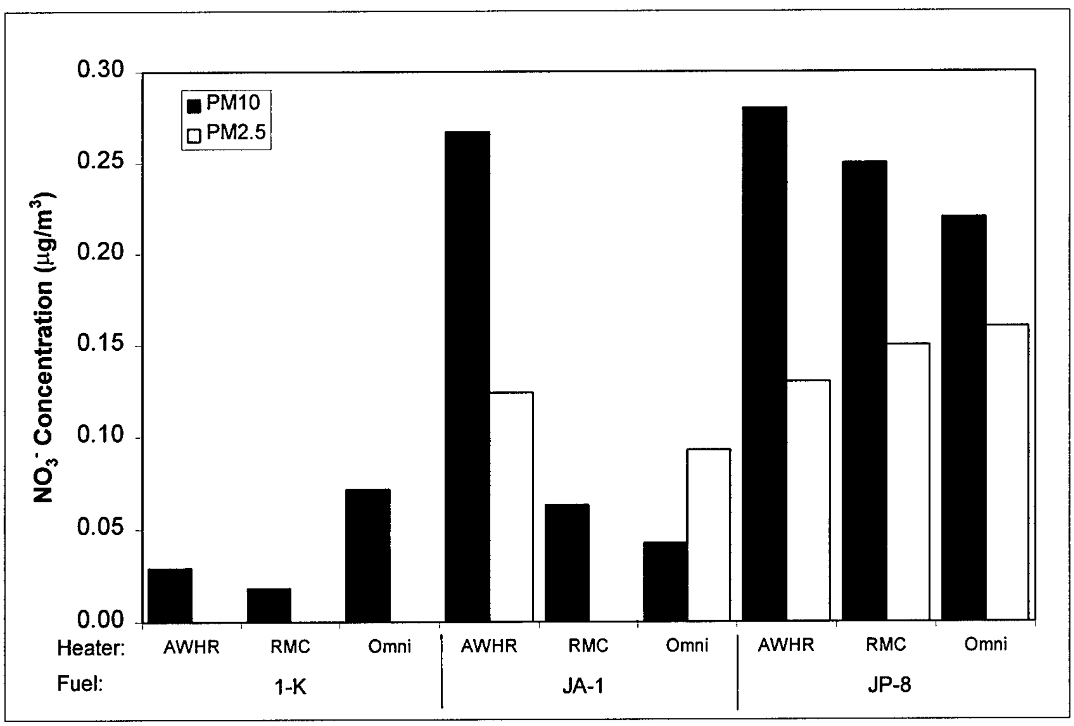


Fig. 20. The NO_3^- concentrations from the ion chromatography analysis when tent doors were closed. The air exchange rate ranged from 1.0 to 1.43 h^{-1}.

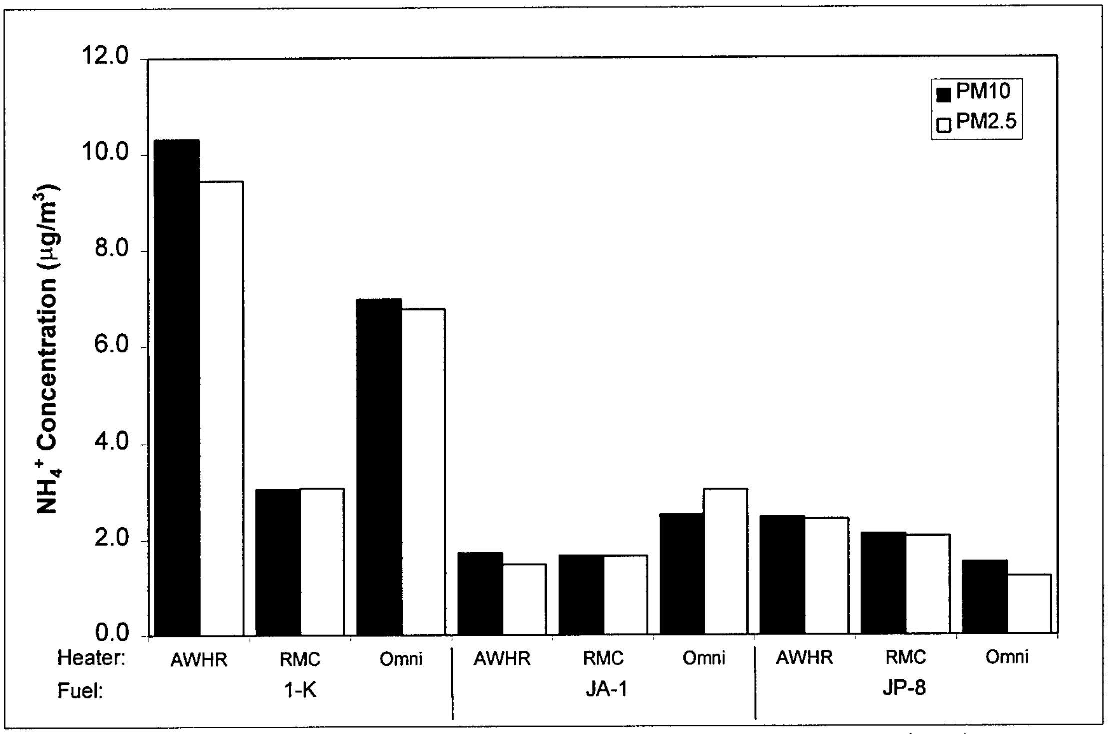


Fig. 21. The NH_4^+ concentrations from the ion chromatography analysis when tent doors were closed. The air exchange rate ranged from 1.0 to 1.43 h^{-1}.

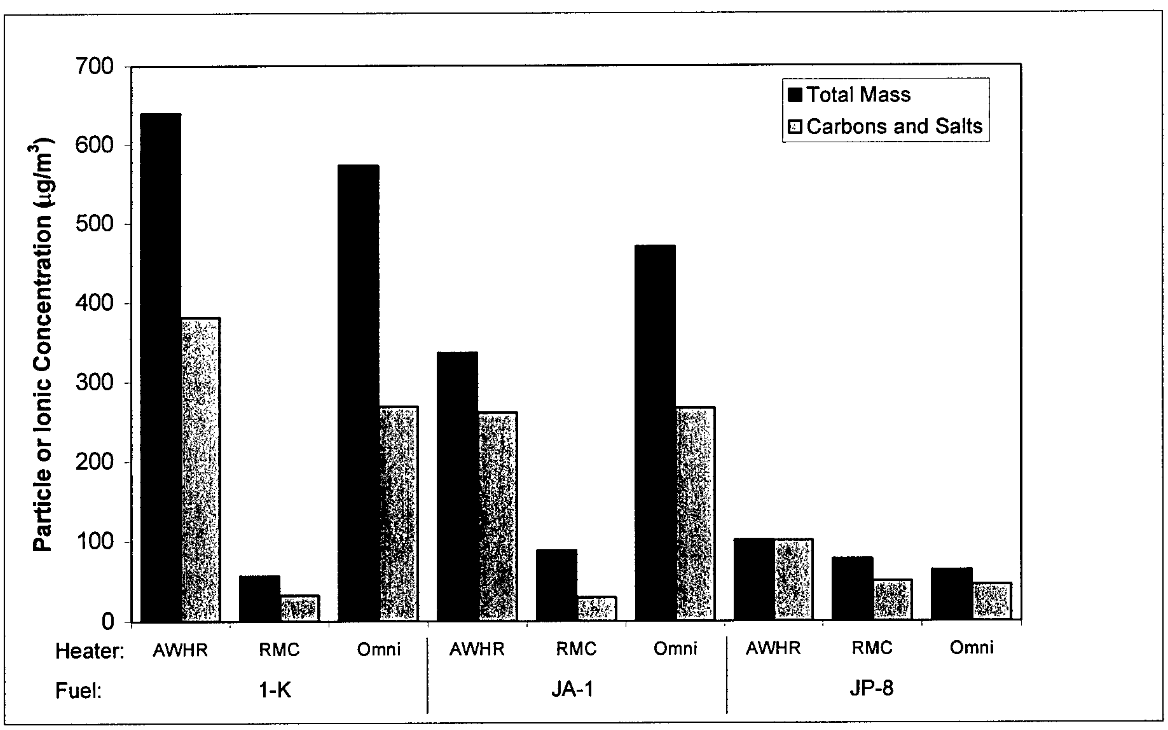


Fig. 22. Comparison of the total particle concentration and the total ion and carbon concentration when the tent doors were closed.

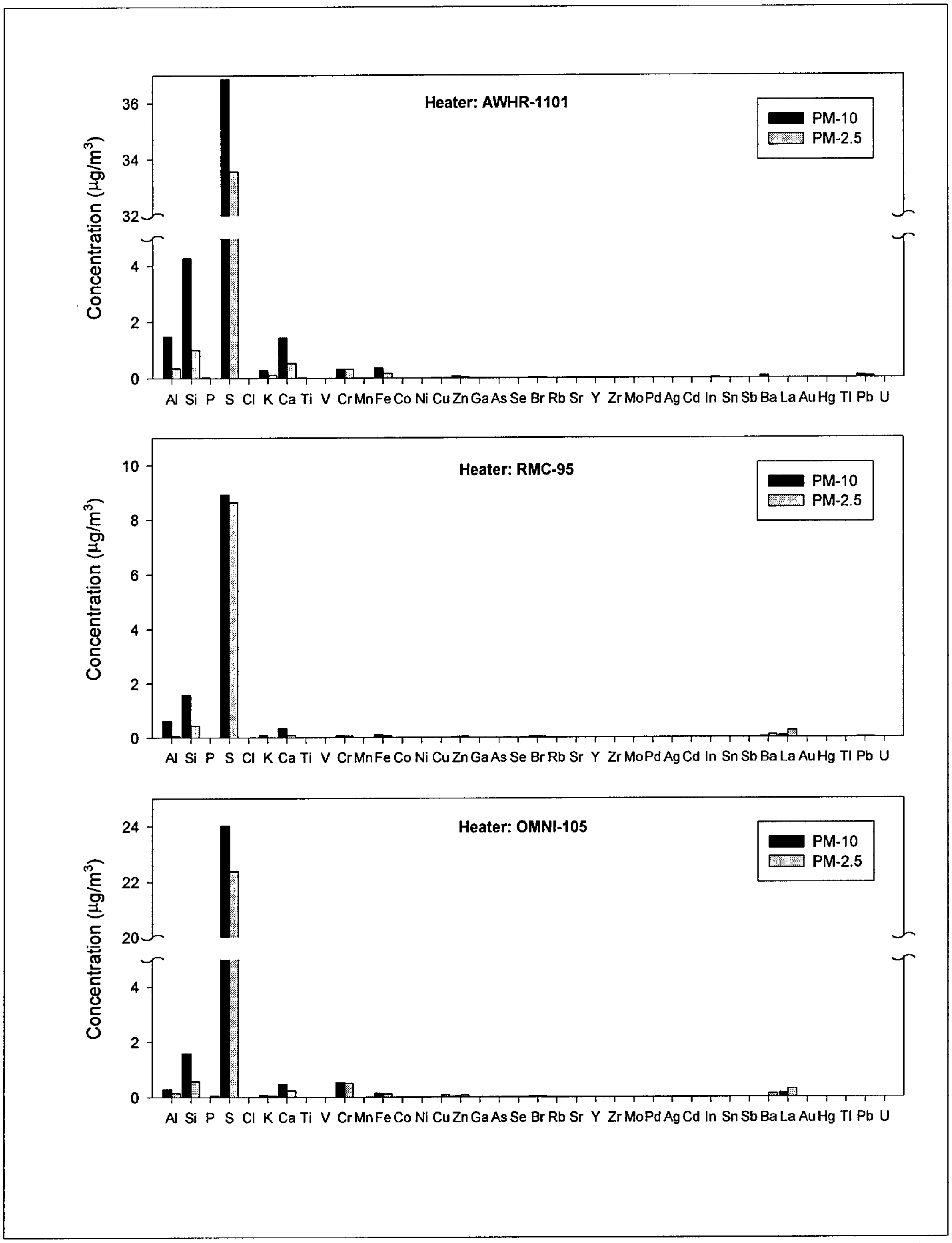


Fig. 23. Elemental analysis results for the 1-K fuel with the different heaters when the tent doors were closed.

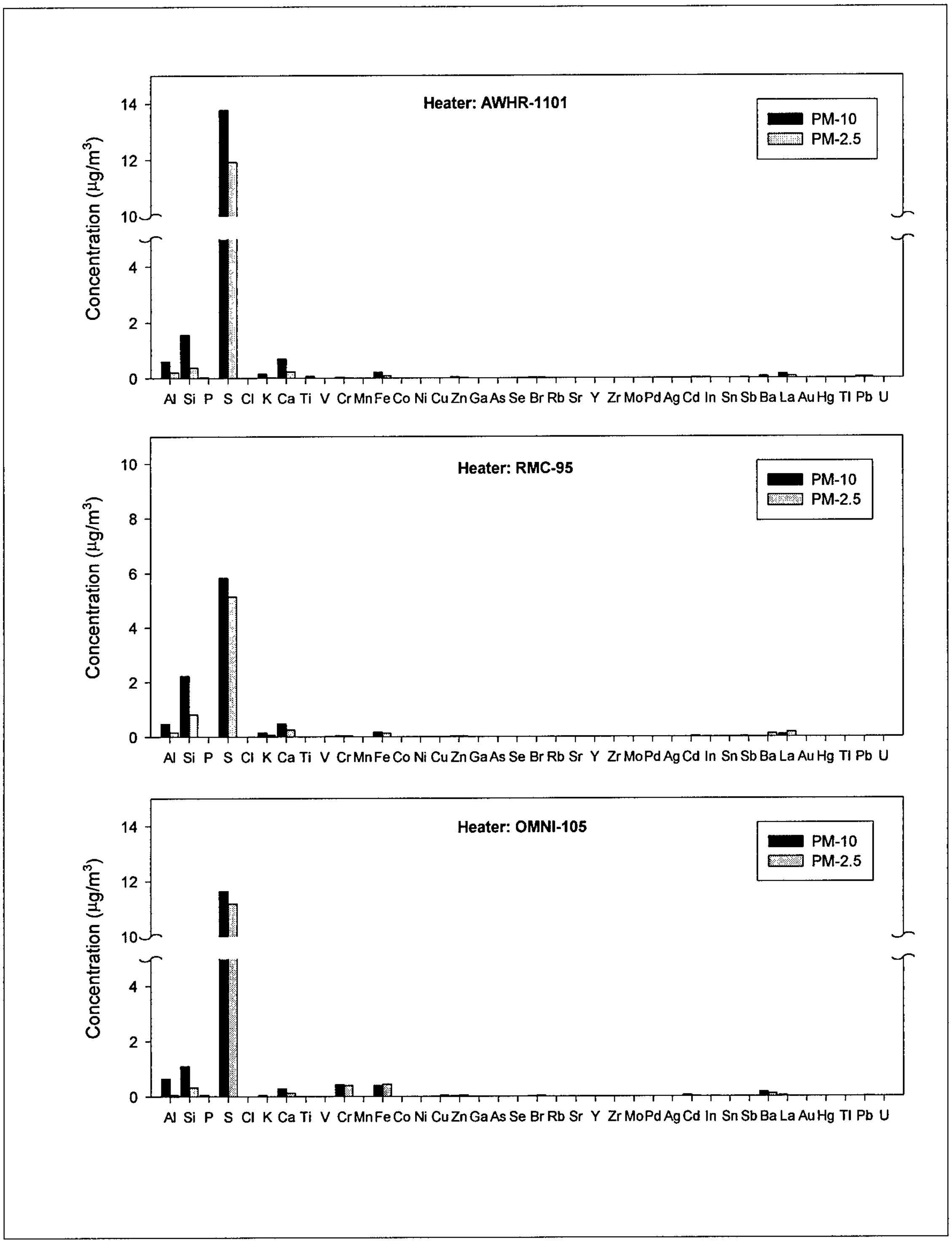


Fig. 24. Elemental analysis results for the JA-1 fuel with the different heaters when the tent doors were closed.

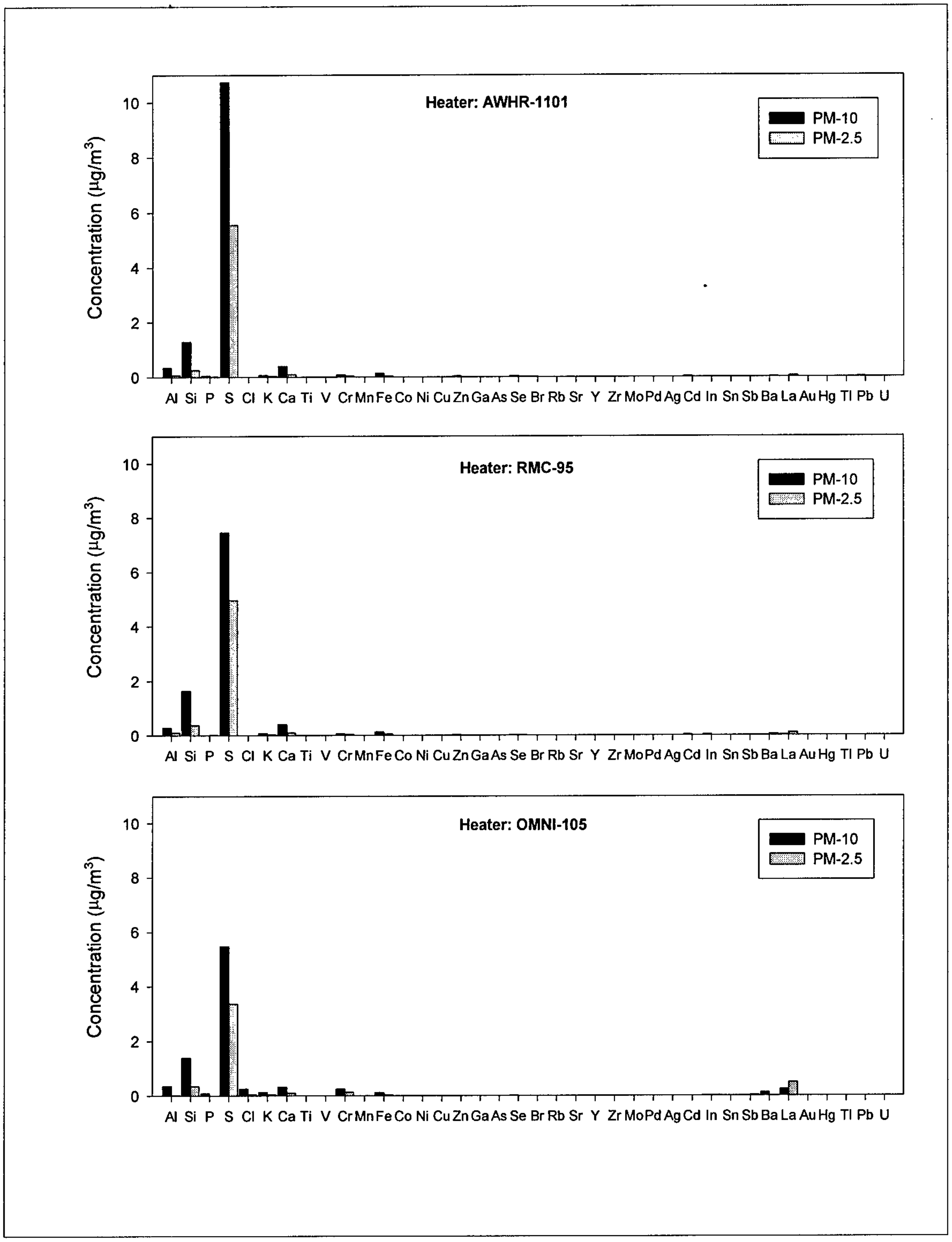


Fig. 25. Elemental analysis results for the JP-8 fuel with the different heaters when the tent doors were closed.

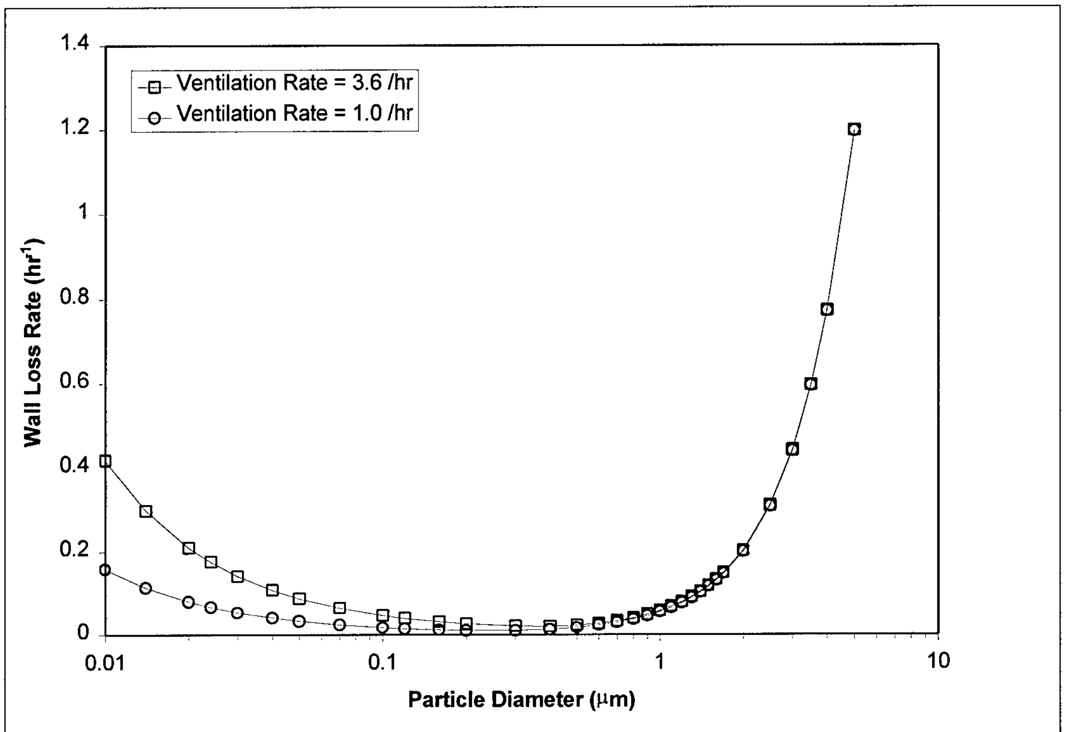


Fig. 26. The wall loss rates when the air exchange rate ranged from 1 to 3.6 h^{-1}.

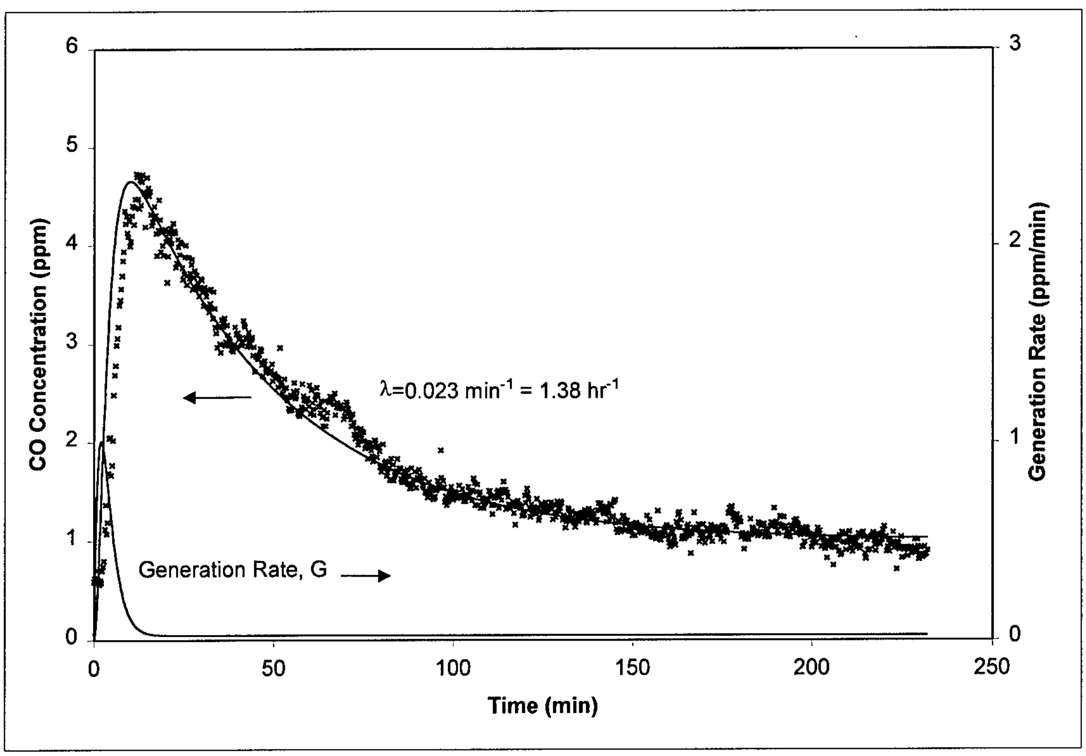


Fig. 27. An example of generation rate regressions for the CO concentration with the AWHR heater and JA-1 fuel. The air exchange rate was 1.36 h^{-1}.

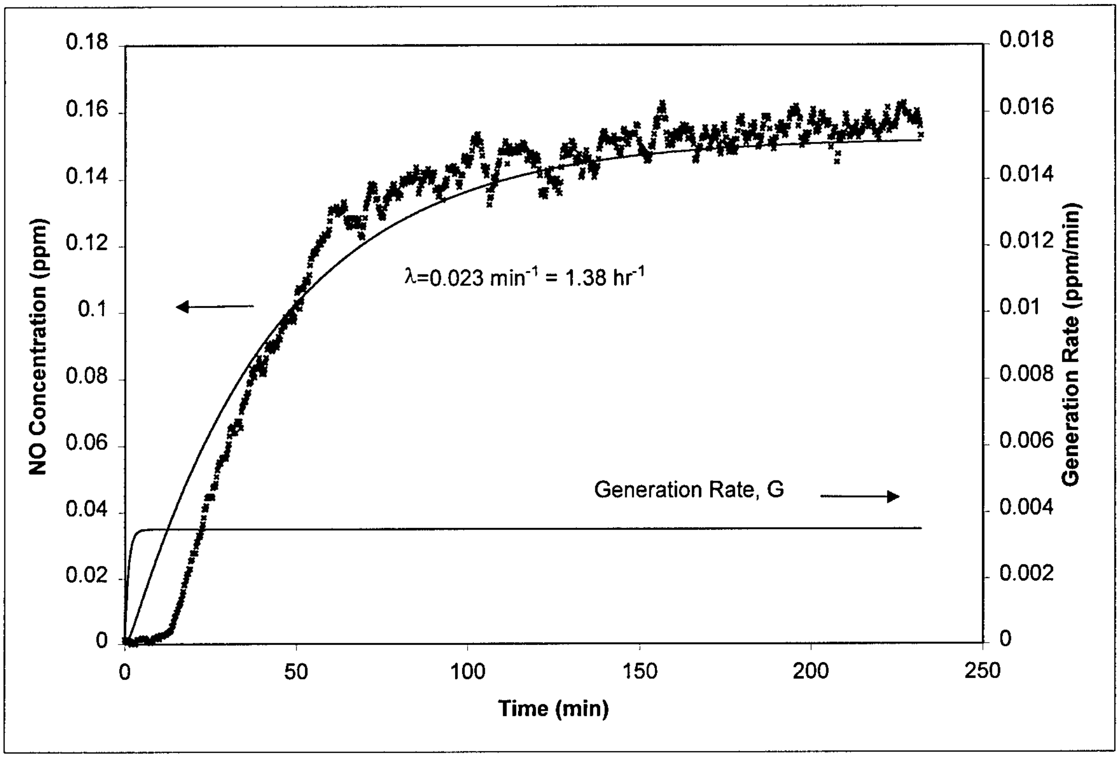


Fig. 28. An example of generation rate regressions for the NO concentration with the AWHR heater and JA-1 fuel. The air exchange rate was 1.36 h^{-1}.

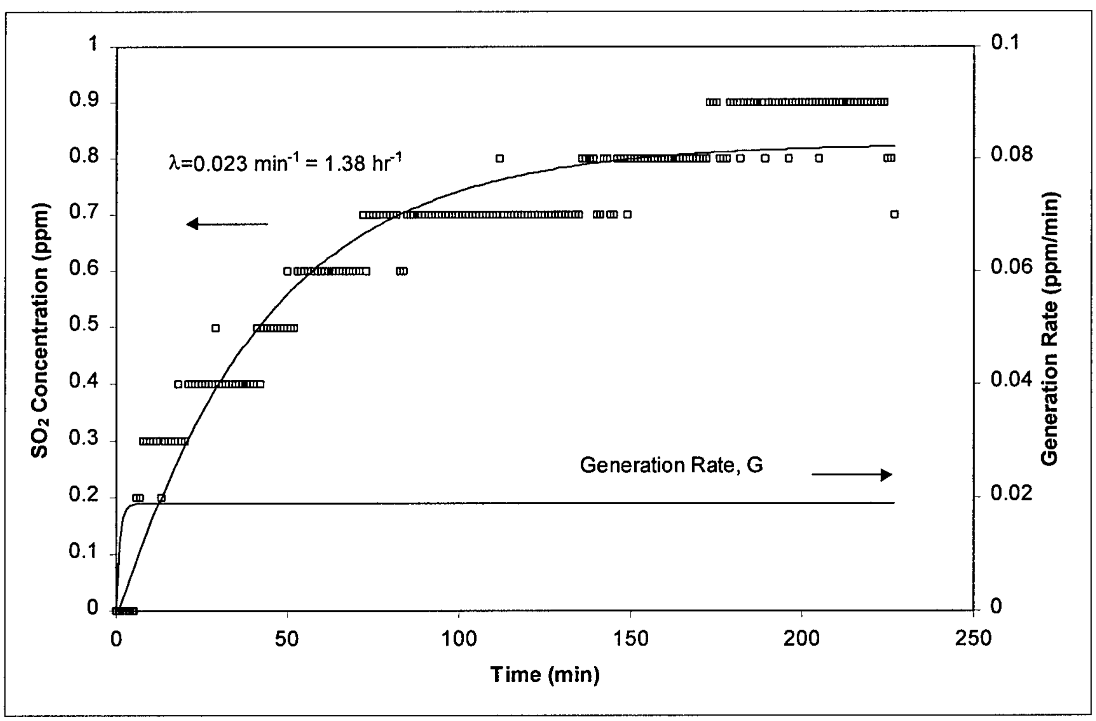


Fig. 29. An example of generation rate regressions for the SO_2 concentration with the AWHR heater and JA-1 fuel. The air exchange rate was 1.36 h^{-1}.

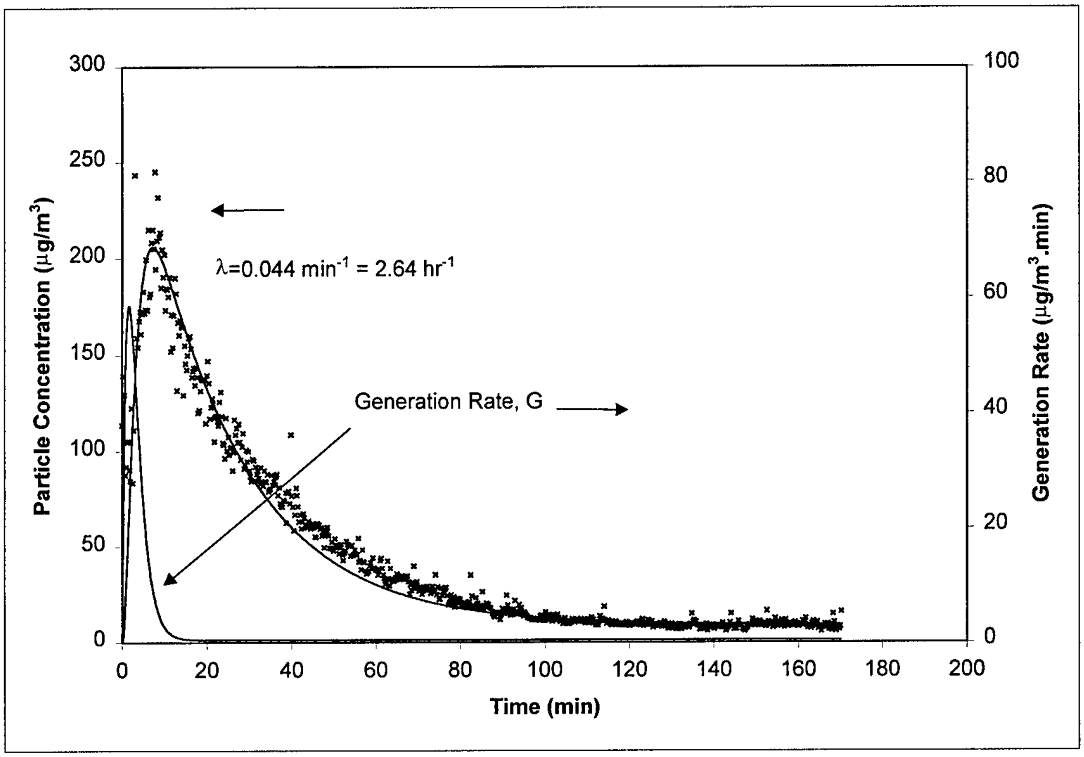


Fig. 30. An example of generation rate regressions for particle concentrations with the Omni heater and JP-8 fuel. The air exchange rate was 2.62 h^{-1}.

LIST OF TABLES

Table 1. Heater specifications and fuel characteristics.

Heaters	AWHR-1101	OMNI-105	RMC-95
Type	Radiant Reflection	Convection	Convection
Fuel Consumption, L/h	0.265	0.628	0.632
Heater Output, Max. kJ/h	11,160	24,210	23,470
Fuel	**1-K Kerosene**	**JA-1 Jet Fuel**	**JP-8 Jet Fuel**
Cetane Index	41.8	45.3	43.3
Distillation Range			
IBP, °F	340.0	350.6	341.7
10 % point, °F	356.9	375.6	362.9
50 % point, °F	396.1	414.0	395.9
90 % point, °F	477.3	468.0	448.1
End point, °F	516.2	495.1	482.5
Flash point, °F	130.0	130.0	132.0
Gravity, °API	43.4	43.1	44.2
Viscosity, CSt @ 40 °C	1.377	1.435	1.319
Aromatics			
Vol. % Aromatics	15.8	20.9	17.0
Vol. % Olefins	4.1	2.4	1.5
Hydrocarbons, Vol. % Saturates	80.1	76.7	81.5
Sulfur, mass %	0.0076	0.0119	0.0245
Lead, ppm	< 0.1	< 0.1	< 0.1
Net Heat, kJ/L	34,902	34,908	34,743

Table 2. PM-2.5 and PM-10 concentration ratio of the specific points to the central point.

	B/A	C/A	D/A	E/A
PM-2.5	0.75	1.45	0.85	0.99
PM-10	0.88	1.31	1.11	1.22

Table 3. Generation rate, total generated concentration, and generation factors for all pollutants with different types of heaters and fuels.

Fuel	Heater	Gas or Particle	Generation Rate (G) ($\mu g \cdot m^{-3} \cdot min^{-1}$ or $ppm \cdot min^{-1}$)*	TG ($\mu g/m^3$)	GF ($\mu g/kJ$)
1-K	Omni-105	NO	$0.0285 \cdot (1-\exp(-t))$	7682.14	9.29
	Omni-105	SO_2	$0.036 \cdot (1-\exp(-t))$	20701.35	25.03
	Omni-105	Particle	$0.35+57.6 \cdot t \cdot \exp(-0.6 \cdot t)$	244.00	0.30
	RMC-95	NO	$0.025 \cdot (1-\exp(-t))$	6738.72	8.10
	RMC-95	Particle	$0.12+61.4 \cdot t \cdot \exp(-0.6 \cdot t)$	199.36	0.24
	AWHR-1101	NO	$0.0028 \cdot (1-\exp(-t))$	754.74	2.16
	AWHR-1101	CO	$0.002+1.6 \cdot t \cdot \exp(-0.5 \cdot t)$	7242.11	20.75
	AWHR-1101	Particle	$0.21+101.5 \cdot t \cdot \exp(-0.6 \cdot t)$	332.34	0.95
JA-1	Omni-105	NO	$0.03 \cdot (1-\exp(-t))$	8086.47	9.78
	Omni-105	SO_2	$0.063 \cdot (1-\exp(-t))$	36227.37	43.79
	Omni-105	CO	$0.003+0.36 \cdot t \cdot \exp(-0.5 \cdot t)$	2273.68	2.75
	Omni-105	Particle	$0.32+46.7 \cdot t \cdot \exp(-0.6 \cdot t)$	206.52	0.25
	RMC-95	NO	$0.041 \cdot (1-\exp(-t))$	11051.50	13.27
	RMC-95	CO	$0.0083+0.335 \cdot t \cdot \exp(-0.5 \cdot t)$	3507.37	4.21
	RMC-95	Particle	$0.3+35.7 \cdot t \cdot \exp(-0.6 \cdot t)$	171.17	0.21
	AWHR-1101	NO	$0.0035 \cdot (1-\exp(-t))$	943.42	2.70
	AWHR-1101	CO	$0.017+1.62 \cdot t \cdot \exp(-0.5 \cdot t)$	11115.79	31.84
	AWHR-1101	Particle	$0.335+41.8 \cdot t \cdot \exp(-0.6 \cdot t)$	196.51	0.56
JP-8	Omni-105	NO	$0.0373 \cdot (1-\exp(-t))$	10054.17	12.21
	Omni-105	Particle	$0.3+80.3 \cdot t \cdot \exp(-0.6 \cdot t)$	295.06	0.36
	RMC-95	NO	$0.03 \cdot (1-\exp(-t))$	8086.47	9.76
	RMC-95	Particle	$0.19+13.5 \cdot t \cdot \exp(-0.6 \cdot t)$	83.10	0.10
	AWHR-1101	NO	$0.0036 \cdot (1-\exp(-t))$	970.38	2.79
	AWHR-1101	CO	$0.017+1.322 \cdot t \cdot \exp(-0.5 \cdot t)$	9861.05	28.38
	AWHR-1101	SO_2	$0.02 \cdot (1-\exp(-t))$	11500.75	33.10
	AWHR-1101	Particle	$0.28+54.9 \cdot t \cdot \exp(-0.6 \cdot t)$	219.70	0.63

* The unit of the generation rate is $mg \cdot m^{-3} \cdot min^{-1}$ for particles or $ppm \cdot min^{-1}$ for gases

TG = Total generation concentrations in 4 hours

GF = Generation factor

Table 4. Comparison of emission factors from the present study with the studies of Traynor et al. (1983, 1990) and Apte & Traynor (1986).

	Traynor et al., 1983		Apte & Traynor, 1986		Traynor et al., 1990		This Study	
Heater Type	Con.	Rad.	Con.	Rad.	Con.	Rad.	Con.	Rad.
CO, μg/kJ	12.4	60.2	25.0	64.0	20.0	84.2	3.48	27.0
NO, μg/kJ	24.5	1.4	14.1	1.3	21.5	0.69	10.4	2.55
SO_2, μg/kJ	-	-	-	-	-	-	34.4	33.1
Particle, μg/kJ	-	-	-	0.49	40.0	0.2	0.24	0.71

Con. = Convection; Rad. = Radiant Reflection

Table 5. Particle deposition fractions for sleeping and resting in the NOPL, TB, and P regions.

Particle Mean Diameter (μm)	Deposition Fraction for Sleeping (%) VT = 625 ml; f_R = 12 min^{-1}								Deposition Fraction for Rest (%) VT = 750 ml; f_R = 12 min^{-1}							
	NOPL		TB		P		TOTAL		NOPL		TB		P		TOTAL	
	NB	MB	NB	MB	NB	MB	NB	MB	NB	MB	NB	MB	NB	MB	NB	MB
0.024	8.42	8.85	36.44	36.11	26.39	26.15	71.25	71.11	8.00	8.46	35.30	34.98	31.08	30.80	74.38	74.24
0.075	3.60	3.64	13.94	13.9	26.59	26.50	44.13	44.04	3.45	3.51	12.96	12.91	30.27	30.18	46.68	46.60
0.134	2.40	2.41	8.14	8.12	18.94	18.90	29.48	29.43	2.32	2.33	7.46	7.45	21.63	21.58	31.41	31.36
0.240	1.62	1.66	4.89	4.88	12.82	12.80	19.33	19.34	1.57	1.63	4.45	4.44	14.72	14.70	20.74	20.77
0.423	2.81	1.29	3.27	3.29	9.57	9.62	15.65	14.20	3.32	1.29	2.96	2.98	11.06	11.15	17.34	15.42
0.748	8.12	1.28	2.79	2.88	9.69	9.98	20.60	14.14	9.50	1.35	2.52	2.61	11.25	11.66	23.27	15.62
1.342	20.83	1.94	3.67	4.03	14.64	16.09	39.14	22.06	23.65	2.19	3.28	3.67	16.70	18.68	43.63	24.54
2.400	40.35	4.11	6.14	7.97	21.53	27.97	68.02	40.05	43.68	4.75	5.47	7.40	23.25	31.46	72.40	43.61
4.233	57.98	9.67	8.98	16.39	17.59	32.12	84.55	58.18	60.35	11.17	7.90	15.51	18.06	35.47	86.31	62.15
7.483	68.21	23.02	9.45	28.65	5.79	17.54	83.45	69.21	69.52	26.19	8.20	26.97	5.91	19.44	83.63	72.60
13.416	67.87	46.09	5.62	25.18	0.37	1.66	73.86	72.93	68.39	50.18	4.92	22.13	0.42	1.90	73.73	74.21
18.000	64.61	55.50	3.43	14.02	0.30	0.11	68.34	69.63	64.90	58.38	3.02	11.04	0.30	0.13	68.22	69.55

NOPL = Naso-Oro-Pharyngolaryngeal
TB = Tracheobronchial
P = Pulmonary
NB = Nose Breathing
MB = Mouth Breathing

Table 6. Particle deposition for the normal augmenters and the mouth breathers.

Fuel Type	Heater Type	TPS* (mg)	TPR* (mg)	Particle Deposition Dose (mg)							
				Normal Augmenters				Mouth Breathers			
				NOPL	TB	P	TOTAL	NOPL	TB	P	TOTAL
1-K	Omni-105	1.332	0.340	0.384	0.182	0.243	0.809	0.338	0.195	0.250	0.783
	RMC-95	0.873	0.262	0.340	0.129	0.156	0.625	0.294	0.146	0.164	0.604
	AWHR-1101	1.469	0.441	0.404	0.232	0.332	0.968	0.343	0.249	0.345	0.937
JA-1	Omni-105	1.158	0.347	0.265	0.151	0.223	0.640	0.233	0.161	0.228	0.621
	RMC-95	1.005	0.302	0.346	0.116	0.172	0.634	0.296	0.133	0.182	0.610
	AWHR-1101	1.142	0.342	0.175	0.148	0.251	0.573	0.148	0.153	0.255	0.556
JP-8	Omni-105	1.451	0.435	0.313	0.160	0.297	0.770	0.256	0.172	0.309	0.738
	RMC-95	0.545	0.163	0.131	0.076	0.108	0.316	0.114	0.082	0.112	0.307
	AWHR-1101	1.154	0.346	0.215	0.173	0.241	0.629	0.188	0.179	0.245	0.613

* TPS = Total particles inhaled while sleeping; TPR = Total particles inhaled while resting

APPENDIX II. OVERALL RESULTS OF THE EXPERIMENTS

Table AI1. Emission data with 1-K kerosene.

Heater	AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})	1.00	1.08	1.22	1.92	2.13	1.84	3.30	3.08	3.22
Temperature, 8 ft (°C)	38.30	N/A	45.70	26.40	43.40	42.80	28.80	38.00	39.40
Temperature, 4 ft (°C)	34.10	N/A	35.10	21.00	28.20	29.40	23.10	21.40	27.30
Temperature, 1 ft (°C)	26.20	16.50	25.50	14.20	18.10	20.20	15.20	12.80	19.10
Temp. corner 4 ft (°C)	30.00	N/A	32.30	18.80	31.60	32.70	21.80	29.20	29.20
Temperature, out (°C)	25.70	6.80	22.20	11.90	17.40	19.80	14.10	14.10	16.60
RH, inside (%)	20.00	50.50	31.90	20.30	18.00	17.90	25.00	19.70	22.00
RH, outside (%)	17.90	62.20	32.00	22.50	20.60	21.70	28.10	22.2	27.10
NO mean (ppm)	0.130	1.170	1.250	0.129	0.375	0.457	0.125	0.087	0.304
NO peak (ppm)	0.210	1.560	1.650	0.320	0.622	0.738	0.346	0.258	0.430
CO mean (ppm)	1.140	1.210	1.770	N/A	N/A	N/A	N/A	N/A	N/A
CO peak (ppm)	9.420	1.870	2.730	N/A	N/A	N/A	N/A	N/A	N/A
CO mean, Multi (ppm)	1.350	0.000	1.710	0.560	0.000	0.000	0.910	0.000	0.620
CO peak, Multi (ppm)	16.000	0.000	5.000	17.000	0.000	0.000	16.00	0.000	7.000
SO_2 mean, Multi (ppm)	0.190	0.000	1.420	0.001	0.000	0.240	0.007	0.000	0.060
SO_2 peak, Multi (ppm)	0.500	0.000	1.800	0.200	0.000	0.700	0.300	0.000	0.500
NO_2 mean, Multi (ppm)	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO_2 peak, Multi (ppm)	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 mean, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 peak, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table AI1 (concluded). Emission data with 1-K kerosene.

Heater		AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})		1.00	1.08	1.22	1.92	2.13	1.84	3.30	3.08	3.22
Particle Concentration ($\mu g/m^3$)										
PM-2.5	A	528.0	493.2	479.8	41.5	26.5	49.8	31.4	13.9	28.5
	B	811.5	245.0	483.4	42.2	20.6	66.9	35.6	17.2	36.4
	C	694.7	215.0	470.0	35.6	33.2	59.6	35.2	19.4	31.8
	Average	678.1	317.7	477.7	39.8	26.8	58.8	34.1	16.9	32.2
PM-10	A	881.1	407.7	611.2	52.9	29.4	50.5	34.6	22.5	31.2
	B	699.2	56.8	678.0	40.2	28.1	68.7	47.0	26.4	40.3
	C	982.7	505.5	626.5	46.1	29.7	63.3	46.7	28.3	33.0
	Average	854.3	323.3	638.6	46.4	29.0	60.8	42.8	25.7	34.8
MOUDI Impactor										
Stage	Cut-Size (μm)									
Filter	0	111.7	80.8	84.9	7.0	4.3	10.2	7.5	3.8	7.2
10	0.056	65.3	42.6	30.0	8.2	2.5	5.2	3.2	5.1	3.0
9	0.1	145.3	105.2	101.8	7.4	3.4	7.0	3.7	5.5	5.2
8	0.18	191.0	60.2	138.5	5.4	5.1	8.0	3.9	3.2	3.8
7	0.32	146.6	101.4	91.4	9.3	2.2	10.7	4.3	1.8	3.1
6	0.56	41.3	9.1	26.6	2.6	2.2	2.3	1.9	3.2	2.1
5	1	6.4	7.6	4.6	1.0	1.3	2.7	1.6	2.2	1.9
4	1.8	6.2	4.5	7.0	1.0	0.9	3.2	2.4	3.1	2.3
3	3.2	5.9	5.8	5.7	0.9	0.5	3.4	2.9	4.0	2.3
2	5.6	5.7	3.2	7.2	0.9	1.7	3.5	2.5	4.8	2.3
1	10	5.4	3.3	6.2	2.0	3.8	4.7	3.9	8.1	2.3
0	18	4.5	7.4	8.8	2.2	1.9	2.9	2.9	5.7	4.7
Total		735.2	430.9	512.4	47.7	29.7	63.8	40.7	50.6	40.4

Table AI2. Emission data from JA-1 Jet Fuel.

Heater	AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})	1.36	1.13	1.31	2.41	2.24	2.28	3.20	3.44	3.59
Temperature, 8 ft (°C)	25.30	36.40	45.30	41.10	39.30	37.40	31.50	40.60	47.10
Temperature, 4 ft (°C)	21.40	27.10	35.80	36.60	28.10	26.90	27.20	26.80	34.30
Temperature, 1 ft (°C)	15.60	18.40	24.60	27.20	17.40	18.10	18.70	17.80	26.10
Temp. corner 4 ft (°C)	17.20	25.40	33.20	32.40	27.10	27.60	23.00	33.80	39.10
Temperature, out (°C)	11.20	14.10	21.40	27.90	15.30	15.10	17.90	17.40	25.10
RH, inside (%)	28.90	30.70	22.40	8.20	23.20	19.20	23.90	17.70	11.00
RH, outside (%)	31.60	33.20	23.00	9.30	31.20	30.60	31.40	24.10	13.70
NO mean (ppm)	0.105	1.612	1.642	0.050	0.769	0.498	0.000	0.065	0.034
NO peak (ppm)	0.145	2.220	2.016	0.084	1.431	0.670	0.078	0.302	0.127
CO mean (ppm)	1.810	0.473	0.000	0.780	0.454	0.078	0.011	0.266	0.000
CO peak (ppm)	4.735	1.234	1.207	6.744	1.489	0.849	1.558	1.612	0.720
CO mean, Multi (ppm)	0.980	0.050	2.140	0.167	0.000	0.000	0.000	0.000	0.000
CO peak, Multi (ppm)	5.000	3.000	6.000	6.000	0.000	0.000	0.000	0.000	0.000
SO_2 mean, Multi (ppm)	0.640	0.000	1.500	0.062	0.440	0.000	0.000	0.000	0.005
SO_2 peak, Multi (ppm)	0.900	0.000	2.500	0.300	0.900	0.000	0.000	0.000	0.200
NO_2 mean, Multi (ppm)	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO_2 peak, Multi (ppm)	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 mean, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 peak, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table AI2 (concluded). Emission data from JA-1 Jet Fuel.

Heater		AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})		1.36	1.13	1.31	2.41	2.24	2.28	3.20	3.44	3.59
Particle Concentration ($\mu g/m^3$)										
PM-2.5	A	350.0	59.3	368.4	34.0	107.1	17.9	31.3	17.9	16.9
	B	356.4	66.5	364.4	32.0	112.1	15.8	26.3	15.1	17.7
	C	326.9	89.8	399.6	32.0	101.7	17.5	24.2	16.3	19.7
	Average	344.4	71.9	377.5	32.6	106.9	17.1	27.2	16.4	18.1
PM-10	A	424.8	128.4	537.5	43.6	114.6	27.1	33.3	20.2	29.3
	B	332.5	115.3	430.8	51.5	106.2	24.6	34.6	22.6	26.9
	C	367.1	104.7	510.3	51.5	112.5	33.8	32.5	23.4	30.1
	Average	374.8	116.1	492.9	48.8	111.1	28.5	33.5	22.1	28.8
MOUDI Impactor										
Stage	Cut-Size (μm)									
Filter	0	9.8	9.0	63.6	8.0	8.9	9.2	6.8	5.0	6.8
10	0.056	31.2	8.8	16.7	4.1	7.9	3.6	3.7	2.0	1.7
9	0.1	72.4	13.0	74.6	8.4	31.1	5.8	5.6	5.3	4.3
8	0.18	116.7	20.1	105.8	12.0	26.4	8.9	8.9	4.4	5.5
7	0.32	90.3	19.5	155.3	8.7	11.9	6.0	6.1	2.0	7.9
6	0.56	21.5	6.8	78.0	4.8	3.9	2.2	3.3	1.7	3.1
5	1	11.5	5.6	6.7	3.0	5.0	2.4	1.4	1.5	1.3
4	1.8	10.0	7.5	1.3	2.9	3.2	3.1	3.1	0.9	1.2
3	3.2	5.7	6.6	7.1	1.0	4.4	2.2	1.9	0.7	1.6
2	5.6	6.0	4.7	16.2	1.7	3.1	3.3	1.8	2.2	1.6
1	10	5.6	4.4	22.9	1.1	4.7	1.9	3.2	2.4	0.7
0	18	3.1	5.4	8.7	1.7	6.0	3.8	2.2	3.0	4.1
Total		383.8	111.3	557.0	57.5	116.5	52.4	48.1	31.1	39.9

Table AI3. Emission data from JP-8 Jet Fuel.

Heater	AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})	1.19	1.43	1.37	2.12	2.29	2.04	3.31	3.55	3.52
Temperature, 8 ft (°C)	35.10	39.20	43.50	39.20	39.10	38.70	34.90	48.70	45.90
Temperature, 4 ft (°C)	30.50	28.20	33.70	34.40	27.00	26.80	30.40	34.80	33.30
Temperature, 1 ft (°C)	22.90	19.10	23.20	26.20	16.30	17.10	21.30	26.00	23.70
Temp. corner 4 ft (°C)	25.90	26.40	32.00	30.30	27.90	28.00	27.60	40.20	38.10
Temperature, out (°C)	19.30	12.10	18.80	23.90	12.00	12.90	22.70	25.40	24.30
RH, inside (%)	20.00	23.80	13.60	16.40	20.50	20.00	18.30	12.10	14.70
RH, outside (%)	23.70	32.80	16.20	22.60	31.50	32.80	23.90	16.50	20.50
NO mean (ppm)	0.120	1.437	1.508	0.012	0.603	0.426	0.000	0.035	0.037
NO peak (ppm)	0.172	1.835	1.942	0.052	0.904	0.866	0.000	0.170	0.143
CO mean (ppm)	1.125	1.590	0.532	0.813	0.276	0.520	0.510	0.747	0.354
CO peak (ppm)	3.942	7.569	1.099	6.540	0.701	2.238	3.579	1.286	1.135
CO mean, Multi (ppm)	0.450	0.586	0.017	0.311	0.000	0.000	0.085	0.000	0.000
CO peak, Multi (ppm)	8.000	4.000	2.000	7.000	0.000	0.000	8.000	0.000	0.000
SO_2 mean, Multi (ppm)	0.140	0.000	0.105	0.009	0.000	0.000	0.000	0.002	0.010
SO_2 peak, Multi (ppm)	0.400	0.000	0.300	0.200	0.000	0.000	0.000	0.200	0.200
NO_2 mean, Multi (ppm)	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO_2 peak, Multi (ppm)	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 mean, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 peak, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table AI3 (concluded). Emission data from JP-8 Jet Fuel.

Heater		AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})		1.19	1.43	1.37	2.12	2.29	2.04	3.31	3.55	3.52
Particle Concentration ($\mu g/m^3$)										
PM-2.5	A	91.4	45.4	62.5	33.3	59.6	40.4	37.9	32.1	38.3
	B	98.8	66.3	57.5	38.3	58.3	35.8	34.6	28.4	36.7
	C	125.7	70.0	65.0	43.8	72.1	37.9	35.4	30.0	36.7
	Average	105.3	60.6	61.7	38.5	63.3	38.1	35.9	30.2	37.2
PM-10	A	129.8	80.0	98.8	48.8	67.1	47.9	49.8	33.7	39.2
	B	121.2	82.1	100.8	56.7	79.2	61.7	39.9	36.2	42.5
	C	75.9	87.9	89.6	50.4	81.3	60.4	43.6	29.6	40.0
	Average	109.0	83.3	96.4	51.9	75.8	56.7	44.4	33.2	40.6
MOUDI Impactor										
Stage	Cut-Size (μm)									
Filter	0	18.2	9.4	4.0	8.1	7.4	8.9	11.1	6.3	7.4
10	0.056	6.4	4.9	4.3	5.3	4.6	6.0	2.5	2.3	3.1
9	0.1	19.6	20.8	15.0	9.2	11.1	10.4	4.5	10.2	8.9
8	0.18	24.5	13.5	15.8	11.1	9.6	10.0	10.3	6.3	11.8
7	0.32	18.8	9.9	7.5	6.3	6.5	12.2	9.6	5.9	5.1
6	0.56	8.8	5.0	8.3	2.6	3.8	4.6	3.7	3.6	3.2
5	1	4.8	4.0	5.6	0.8	5.3	5.4	4.5	1.0	2.6
4	1.8	4.2	3.2	1.1	1.8	6.1	6.4	1.8	1.9	1.5
3	3.2	6.7	5.4	1.7	1.1	6.0	3.9	1.1	3.0	2.4
2	5.6	3.1	2.9	0.7	0.1	9.7	5.3	2.1	1.9	2.4
1	10	3.7	5.0	8.3	1.8	6.5	4.6	1.5	1.2	1.1
0	18	6.4	3.5	6.4	3.3	2.8	3.5	3.0	3.7	0.7
Total		125.2	87.5	78.8	51.5	79.3	81.1	55.7	47.3	50.1

Table AI4. Emission data outdoors.

Heater	AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})	2.30	2.55	2.82	3.12	2.91	2.68	2.35	3.23	2.62
Fuel	1-K	1-K	1-K	JA-1	JA-1	JA-1	JP-8	JP-8	JP-8
Temperature, 8 ft (°C)	49.1	57.7	57.2	44.5	54.5	57.5	45.8	53.2	57.3
Temperature, 4 ft (°C)	45.7	51.0	49.4	41.2	46.7	47.9	40.4	43.8	48.3
Temperature, 1 ft (°C)	39.3	41.1	40.6	33.7	37.0	36.7	32.3	32.7	39.0
Temp. corner 4 ft (°C)	45.5	39.5	49.1	39.9	46.6	46.4	40.4	42.0	48.5
Temperature, out (°C)	29.5	29.4	27.3	25.8	26.3	25.5	25.3	23.8	25.3
RH, inside (%)	7.4	6.1	8.3	12.4	12.5	8.4	12.6	13.4	11.7
RH, outside (%)	9.8	9.6	10.5	14.8	16.2	12.0	16.0	18.2	16.1
NO mean (ppm)	0.000	0.687	0.788	0.000	0.593	0.435	N/A	0.307	0.867
NO peak (ppm)	0.000	1.408	1.305	0.000	0.960	0.808	0.039	0.647	1.223
CO mean (ppm)	0.444	0.534	0.450	0.306	0.674	0.747	N/A	0.595	0.850
CO peak (ppm)	0.946	9.702	1.405	4.220	3.134	2.594	7.321	2.048	2.214
CO mean, Multi (ppm)	0.480	0.000	0.000	0.130	0.000	0.000	0.332	0.000	0.011
CO peak, Multi (ppm)	8.00	0.000	0.000	5.000	0.000	0.000	10.00	0.000	2.000
SO_2 mean, Multi (ppm)	0.210	0.210	0.196	0.160	0.138	0.261	0.265	0.195	0.420
SO_2 peak, Multi (ppm)	0.600	0.700	0.700	0.400	0.500	0.600	0.600	0.500	0.700
NO_2 mean, Multi (ppm)	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO_2 peak, Multi (ppm)	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 mean, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH_4 peak, Multi (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table AI4 (concluded). Emission data outdoors.

Heater		AWHR	RMC	Omni	AWHR	RMC	Omni	AWHR	RMC	Omni
Air exchange rate (h^{-1})		2.30	2.55	2.82	3.12	2.91	2.68	2.35	3.23	2.62
Fuel		1-K	1-K	1-K	JA-1	JA-1	JA-1	JP-8	JP-8	JP-8
Particle Concentration ($\mu g/m^3$)										
PM-2.5	A	52.8	29.4	51.7	44.5	48.3	37.9	32.8	41.3	60.6
	B	43.3	26.7	45.0	87.5	51.1	30.0	40.2	37.5	60.6
	C	45.6	31.1	57.8	97.9	56.7	34.6	44.0	30.0	50.5
	Average	47.2	29.1	51.5	76.7	52.0	34.2	39.0	36.3	57.0
PM-10	A	51.7	45.0	53.3	235.8	60.6	41.3	58.9	37.9	77.8
	B	76.7	37.8	82.8	222.1	65.0	54.6	67.2	37.9	57.8
	C	47.8	37.8	61.1	217.1	58.9	52.9	52.7	56.3	69.4
	Average	58.7	40.2	65.7	225.0	61.5	49.6	59.6	44.0	68.3
MOUDI Impactor										
Stage	Cut-Size (μm)									
Filter	0	15.7	12.4	11.9	22.4	6.5	7.9	10.5	11.3	9.6
10	0.056	23.7	4.6	6.7	11.4	6.7	4.4	4.7	2.2	10.6
9	0.1	9.4	6.1	9.6	16.9	10.9	9.6	4.6	3.6	28.1
8	0.18	12.6	9.6	13.7	25.7	12.0	11.7	14.8	8.1	31.1
7	0.32	8.5	3.3	8.9	10.0	10.4	8.9	9.4	9.7	15.4
6	0.56	6.7	6.5	9.3	13.6	4.8	4.2	5.7	2.1	10.7
5	1	2.2	3.5	4.4	14.7	7.2	3.3	4.1	1.5	6.5
4	1.8	4.4	5.6	4.3	24.0	2.2	2.6	3.2	0.7	9.3
3	3.2	9.1	3.1	1.5	43.6	5.2	0.8	1.9	0.3	8.3
2	5.6	8.1	8.5	5.4	51.8	9.1	2.6	3.9	3.1	9.3
1	10	3.1	8.3	3.1	61.1	7.0	2.8	4.3	3.2	1.5
0	18	7.4	8.5	12.6	82.9	8.5	5.4	7.9	5.4	4.4
Total		111.1	80.2	91.3	378.2	90.6	64.3	75.0	51.1	144.8

APPENDIX III. DOSE FOR SPECIFIC PARTICLE SIZE

Table AII1. Normal augmenter dosimetry for 1-K kerosene.

Fuel: 1-K			Total Particles Inhaled while Sleeping:				**1.332** mg					
Heater: OMNI-105			Total Particles Inhaled while Resting:				**0.3996** mg					
Mean Size	Sample Weight	Weight Frction	Inhaled Particles Sleeping	Inhaled Particles Rest	Deposition Value for Sleeping NOPL	TB	P	Total	Deposition Value for Rest NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.064	0.129817	0.1729168	0.0518751	0.01456	0.06301	0.04563	0.1232	0.00415	0.01831	0.01612	0.03858
0.0748	0.036	0.073022	0.0972657	0.0291797	0.0035	0.01356	0.02586	0.04292	0.00101	0.00378	0.00883	0.01362
0.1342	0.052	0.105477	0.1404949	0.0421485	0.00337	0.01144	0.02661	0.04142	0.00098	0.00314	0.00912	0.01324
0.24	0.074	0.150101	0.1999351	0.0599805	0.00324	0.00978	0.02563	0.03865	0.00094	0.00267	0.00883	0.01244
0.4233	0.048	0.097363	0.1296876	0.0389063	0.00364	0.00424	0.01241	0.0203	0.00129	0.00115	0.0043	0.00675
0.7483	0.05	0.10142	0.1350913	0.0405274	0.01097	0.00377	0.01309	0.02783	0.00385	0.00102	0.00456	0.00943
1.3416	0.024	0.048682	0.0648438	0.0194531	0.01351	0.00238	0.00949	0.02538	0.0046	0.00064	0.00325	0.00849
2.4	0.023	0.046653	0.062142	0.0186426	0.02507	0.00382	0.01338	0.04227	0.00814	0.00102	0.00433	0.0135
4.2332	0.008	0.016227	0.0216146	0.0064844	0.01253	0.00194	0.0038	0.01828	0.00391	0.00051	0.00117	0.0056
7.4833	0.029	0.058824	0.0783529	0.0235059	0.05344	0.0074	0.00454	0.06539	0.01634	0.00193	0.00139	0.01966
13.416	0.017	0.034483	0.045931	0.0137793	0.03117	0.00258	0.00017	0.03392	0.00942	0.00068	5.8E-05	0.01016
18	0.068	0.137931	0.1837241	0.0551172	0.1187	0.0063	0.00055	0.12556	0.03577	0.01665	0.00017	0.05258
Total	**0.493**	**1**	**1.332**	**0.3996**	**0.2937**	**0.1302**	**0.1812**	**0.6051**	**0.0904**	**0.0515**	**0.0621**	**0.204**

Fuel: 1-K			Total Particle Inhaled while Sleeping:				**0.8732** mg					
Heater: RMC-95			Total Particle Inhaled while Rest:				**0.262** mg					
Mean Size	Sample Weight	Weight Frction	Inhaled Particles Sleeping	Inhaled Particles Rest	Deposition Value for Sleeping NOPL	TB	P	Total	Deposition Value for Rest NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.067	0.154734	0.1351141	0.0405404	0.01138	0.04924	0.03566	0.09627	0.00324	0.01431	0.0126	0.03015
0.0748	0.025	0.057737	0.0504157	0.015127	0.00181	0.00703	0.01341	0.02225	0.00052	0.00196	0.00458	0.00706
0.1342	0.033	0.076212	0.0665487	0.0199677	0.0016	0.00542	0.0126	0.01962	0.00046	0.00149	0.00432	0.00627
0.24	0.052	0.120092	0.1048647	0.0314642	0.0017	0.00513	0.01344	0.02027	0.00049	0.0014	0.00463	0.00653
0.4233	0.018	0.04157	0.0362993	0.0108915	0.00102	0.00119	0.00347	0.00568	0.00036	0.00032	0.0012	0.00189
0.7483	0.035	0.080831	0.070582	0.0211778	0.00573	0.00197	0.00684	0.01454	0.00201	0.00053	0.00238	0.00493
1.3416	0.019	0.04388	0.0383159	0.0114965	0.00798	0.00141	0.00561	0.015	0.00272	0.00038	0.00192	0.00502
2.4	0.03	0.069284	0.0604988	0.0181524	0.02441	0.00371	0.01303	0.04115	0.00793	0.00099	0.00422	0.01314
4.2332	0.017	0.039261	0.0342827	0.0102864	0.01988	0.00308	0.00603	0.02899	0.00621	0.00081	0.00186	0.00888
7.4833	0.046	0.106236	0.0927649	0.0278337	0.06327	0.00877	0.00537	0.07741	0.01935	0.00228	0.00164	0.02328
13.416	0.045	0.103926	0.0907483	0.0272286	0.06159	0.0051	0.00034	0.06703	0.01862	0.00134	0.00011	0.02008
18	0.046	0.106236	0.0927649	0.0278337	0.05994	0.00318	0.00028	0.0634	0.01806	0.00841	8.4E-05	0.02655
Total	**0.433**	**1**	**0.8732**	**0.262**	**0.2603**	**0.0952**	**0.1161**	**0.4716**	**0.08**	**0.0342**	**0.0396**	**0.1538**

Fuel: 1-K			Total Particle Inhaled while Sleeping:				**1.469** mg					
Heater: AWHR-1101			Total Particle Inhaled while Rest:				**0.441** mg					
Mean Size	Sample Weight	Weight Frction	Inhaled Particles Sleeping	Inhaled Particles Rest	Deposition Value for Sleeping NOPL	TB	P	Total	Deposition Value for Rest NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.085	0.141667	0.2081083	0.062475	0.01752	0.07583	0.05492	0.14828	0.005	0.02205	0.01942	0.04647
0.0748	0.128	0.213333	0.3133867	0.09408	0.01128	0.04369	0.08333	0.1383	0.00325	0.01219	0.02848	0.04392
0.1342	0.051	0.085	0.124865	0.037485	0.003	0.01016	0.02365	0.03681	0.00087	0.0028	0.00811	0.01177
0.24	0.068	0.113333	0.1664867	0.04998	0.0027	0.00814	0.02134	0.03218	0.00078	0.00222	0.00736	0.01037
0.4233	0.046	0.076667	0.1126233	0.03381	0.00316	0.00368	0.01078	0.01763	0.00112	0.001	0.00374	0.00586
0.7483	0.036	0.06	0.08814	0.02646	0.00716	0.00246	0.00854	0.01816	0.00251	0.00067	0.00298	0.00616
1.3416	0.012	0.02	0.02938	0.00882	0.00612	0.00108	0.0043	0.0115	0.00209	0.00029	0.00147	0.00385
2.4	0.024	0.04	0.05876	0.01764	0.02371	0.00361	0.01265	0.03997	0.00771	0.00096	0.0041	0.01277
4.2332	0.049	0.081667	0.1199683	0.036015	0.06956	0.01077	0.0211	0.10143	0.02174	0.00285	0.0065	0.03108
7.4833	0.044	0.073333	0.1077267	0.03234	0.07348	0.01018	0.00624	0.0899	0.02248	0.00265	0.00191	0.02705
13.416	0.017	0.028333	0.0416217	0.012495	0.02825	0.00234	0.00015	0.03074	0.00855	0.00061	5.2E-05	0.00921
18	0.04	0.066667	0.0979333	0.0294	0.06327	0.00336	0.00029	0.06693	0.01908	0.00888	8.8E-05	0.02805
Total	**0.6**	**1**	**1.469**	**0.441**	**0.3092**	**0.1753**	**0.2473**	**0.7318**	**0.0952**	**0.0572**	**0.0842**	**0.2366**

Table AII2. Normal augmenter dosimetry for JA-1 Jet Fuel.

Fuel: JA-1			Total Particles Inhaled while Sleeping:				**1.1582** mg					
Heater: OMNI-105			Total Particles Inhaled while Resting:				**0.3475** mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.057	0.12311	0.1425862	0.0427808	0.01201	0.05196	0.03763	0.10159	0.00342	0.0151	0.0133	0.03182
0.0748	0.032	0.069114	0.0800484	0.0240173	0.00288	0.01116	0.02128	0.03533	0.00083	0.00311	0.00727	0.01121
0.1342	0.069	0.149028	0.1726043	0.0517873	0.00414	0.01405	0.03269	0.05088	0.0012	0.00386	0.0112	0.01627
0.24	0.084	0.181425	0.210127	0.0630454	0.0034	0.01028	0.02694	0.04062	0.00099	0.00281	0.00928	0.01308
0.4233	0.064	0.138229	0.1600968	0.0480346	0.0045	0.00524	0.01532	0.02506	0.00159	0.00142	0.00531	0.00833
0.7483	0.03	0.064795	0.0750454	0.0225162	0.00609	0.00209	0.00727	0.01546	0.00214	0.00057	0.00253	0.00524
1.3416	0.024	0.051836	0.0600363	0.018013	0.01251	0.0022	0.00879	0.0235	0.00426	0.00059	0.00301	0.00786
2.4	0.019	0.041037	0.0475287	0.0142603	0.01918	0.00292	0.01023	0.03233	0.00623	0.00078	0.00332	0.01032
4.2332	0.006	0.012959	0.0150091	0.0045032	0.0087	0.00135	0.00264	0.01269	0.00272	0.00036	0.00081	0.00389
7.4833	0.019	0.041037	0.0475287	0.0142603	0.03242	0.00449	0.00275	0.03966	0.00991	0.00117	0.00084	0.01193
13.416	0.02	0.043197	0.0500302	0.0150108	0.03396	0.00281	0.00019	0.03695	0.01027	0.00074	6.3E-05	0.01107
18	0.039	0.084233	0.097559	0.0292711	0.06303	0.00335	0.00029	0.06667	0.019	0.00884	8.8E-05	0.02792
Total	**0.463**	**1**	**1.1582**	**0.3475**	**0.2028**	**0.1119**	**0.166**	**0.4807**	**0.0626**	**0.0393**	**0.057**	**0.1589**

Fuel: JA-1			Total Particle Inhaled while Sleeping:				**1.005** mg					
Heater: RMC-95			Total Particle Inhaled while Rest:				**0.3015** mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.035	0.071575	0.0719325	0.0215798	0.00606	0.02621	0.01898	0.05125	0.00173	0.00762	0.00671	0.01605
0.0748	0.036	0.07362	0.0739877	0.0221963	0.00266	0.01031	0.01967	0.03265	0.00077	0.00288	0.00672	0.01036
0.1342	0.059	0.120654	0.1212577	0.0363773	0.00291	0.00987	0.02297	0.03575	0.00084	0.00271	0.00787	0.01143
0.24	0.065	0.132924	0.133589	0.0400767	0.00216	0.00653	0.01713	0.02582	0.00063	0.00178	0.0059	0.00831
0.4233	0.056	0.114519	0.115092	0.0345276	0.00323	0.00376	0.01101	0.01801	0.00115	0.00102	0.00382	0.00599
0.7483	0.026	0.05317	0.0534356	0.0160307	0.00434	0.00149	0.00518	0.01101	0.00152	0.0004	0.0018	0.00373
1.3416	0.039	0.079755	0.0801534	0.024046	0.0167	0.00294	0.01173	0.03137	0.00569	0.00079	0.00402	0.01049
2.4	0.012	0.02454	0.0246626	0.0073988	0.00995	0.00151	0.00531	0.01678	0.00323	0.0004	0.00172	0.00536
4.2332	0.028	0.05726	0.057546	0.0172638	0.03337	0.00517	0.01012	0.04866	0.01042	0.00136	0.00312	0.0149
7.4833	0.049	0.100204	0.1007055	0.0302117	0.06869	0.00952	0.00583	0.08404	0.021	0.00248	0.00179	0.02527
13.416	0.038	0.07771	0.0780982	0.0234294	0.05301	0.00439	0.00029	0.05768	0.01602	0.00115	9.8E-05	0.01727
18	0.046	0.09407	0.0945399	0.028362	0.06108	0.00324	0.00028	0.06461	0.01841	0.00857	8.5E-05	0.02706
Total	**0.489**	**1**	**1.005**	**0.3015**	**0.2642**	**0.085**	**0.1285**	**0.4776**	**0.0814**	**0.0312**	**0.0436**	**0.1562**

Fuel: JA-1			Total Particle Inhaled while Sleeping:				**1.142** mg					
Heater: AWHR-1101			Total Particle Inhaled while Rest:				**0.342** mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.044	0.113695	0.1298398	0.0388837	0.01093	0.04731	0.03426	0.09251	0.00311	0.01373	0.01209	0.02892
0.0748	0.0455	0.117571	0.1342661	0.0402093	0.00483	0.01872	0.0357	0.05925	0.00139	0.00521	0.01217	0.01877
0.1342	0.074	0.191214	0.2183669	0.0653953	0.00524	0.01778	0.04136	0.06437	0.00152	0.00488	0.01415	0.02054
0.24	0.075	0.193798	0.2213178	0.0662791	0.00359	0.01082	0.02837	0.04278	0.00104	0.00295	0.00976	0.01375
0.4233	0.049	0.126615	0.1445943	0.0433023	0.00406	0.00473	0.01384	0.02263	0.00144	0.00128	0.00479	0.00751
0.7483	0.0285	0.073643	0.0841008	0.025186	0.00683	0.00235	0.00815	0.01732	0.00239	0.00063	0.00283	0.00586
1.3416	0.0215	0.055556	0.0634444	0.019	0.01322	0.00233	0.00929	0.02483	0.00449	0.00062	0.00317	0.00829
2.4	0.014	0.036176	0.0413127	0.0123721	0.01667	0.00254	0.00889	0.0281	0.0054	0.00068	0.00288	0.00896
4.2332	0.0095	0.024548	0.0280336	0.0083953	0.01625	0.00252	0.00493	0.0237	0.00507	0.00066	0.00152	0.00725
7.4833	0.01	0.02584	0.029509	0.0088372	0.02013	0.00279	0.00171	0.02463	0.00614	0.00072	0.00052	0.00739
13.416	0.01	0.02584	0.029509	0.0088372	0.02003	0.00166	0.00011	0.0218	0.00604	0.00043	3.7E-05	0.00652
18	0.006	0.015504	0.0177054	0.0053023	0.01144	0.00061	5.3E-05	0.0121	0.00344	0.0016	1.6E-05	0.00506
Total	**0.387**	**1**	**1.142**	**0.342**	**0.1332**	**0.1141**	**0.1867**	**0.434**	**0.0415**	**0.0334**	**0.0639**	**0.1388**

Table AII3. Normal augmenter dosimetry for JP-8 Jet Fuel.

Fuel: JP-8			Total Particles Inhaled while Sleeping:					1.451 mg				
Heater: OMNI-105			Total Particles Inhaled while Resting:					0.435 mg				
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.052	0.066496	0.0964859	0.0289258	0.00812	0.03516	0.02546	0.06875	0.00231	0.01021	0.00899	0.02152
0.0748	0.057	0.07289	0.1057634	0.0317072	0.00381	0.01474	0.02812	0.04667	0.00109	0.00411	0.0096	0.0148
0.1342	0.152	0.194373	0.2820358	0.0845524	0.00677	0.02296	0.05342	0.08314	0.00196	0.00631	0.01829	0.02656
0.24	0.168	0.214834	0.3117238	0.0934527	0.00505	0.01524	0.03996	0.06026	0.00147	0.00416	0.01376	0.01938
0.4233	0.083	0.106138	0.1540064	0.0461701	0.00433	0.00504	0.01474	0.0241	0.00153	0.00137	0.00511	0.00801
0.7483	0.058	0.074169	0.1076189	0.0322634	0.00874	0.003	0.01043	0.02217	0.00307	0.00081	0.00363	0.00751
1.3416	0.035	0.044757	0.0649425	0.0194693	0.01353	0.00238	0.00951	0.02542	0.0046	0.00064	0.00325	0.00849
2.4	0.05	0.063939	0.0927749	0.0278133	0.03743	0.0057	0.01997	0.06311	0.01215	0.00152	0.00647	0.02014
4.2332	0.045	0.057545	0.0834974	0.025032	0.04841	0.0075	0.01469	0.0706	0.01511	0.00198	0.00452	0.02161
7.4833	0.05	0.063939	0.0927749	0.0278133	0.06328	0.00877	0.00537	0.07742	0.01934	0.00228	0.00164	0.02326
13.416	0.008	0.01023	0.014844	0.0044501	0.01007	0.00083	5.5E-05	0.01096	0.00304	0.00022	1.9E-05	0.00328
18	0.024	0.030691	0.044532	0.0133504	0.02877	0.00153	0.00013	0.03043	0.00866	0.00403	4E-05	0.01274
Total	**0.782**	**1**	**1.451**	**0.435**	**0.2383**	**0.1228**	**0.2219**	**0.583**	**0.0743**	**0.0376**	**0.0753**	**0.1873**

Fuel: JP-8			Total Particle Inhaled while Sleeping:					0.545 mg				
Heater: RMC-95			Total Particle Inhaled while Rest:					0.164 mg				
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.065	0.145197	0.0791325	0.0238124	0.00666	0.02884	0.02088	0.05638	0.0019	0.00841	0.0074	0.01771
0.0748	0.022667	0.050633	0.0275949	0.0083038	0.00099	0.00385	0.00734	0.01218	0.00029	0.00108	0.00251	0.00388
0.1342	0.083333	0.18615	0.101452	0.0305287	0.00243	0.00826	0.01922	0.02991	0.00071	0.00228	0.0066	0.00959
0.24	0.067	0.149665	0.0815674	0.024545	0.00132	0.00399	0.01046	0.01577	0.00039	0.00109	0.00361	0.00509
0.4233	0.061333	0.137007	0.0746687	0.0224691	0.0021	0.00244	0.00715	0.01169	0.00075	0.00067	0.00249	0.0039
0.7483	0.025667	0.057334	0.0312472	0.0094028	0.00254	0.00087	0.00303	0.00644	0.00089	0.00024	0.00106	0.00219
1.3416	0.015667	0.034996	0.019073	0.0057394	0.00397	0.0007	0.00279	0.00747	0.00136	0.00019	0.00096	0.0025
2.4	0.014	0.031273	0.0170439	0.0051288	0.00688	0.00105	0.00367	0.01159	0.00224	0.00028	0.00119	0.00371
4.2332	0.021	0.04691	0.0255659	0.0076932	0.01482	0.0023	0.0045	0.02162	0.00464	0.00061	0.00139	0.00664
7.4833	0.019	0.042442	0.023131	0.0069605	0.01578	0.00219	0.00134	0.0193	0.00484	0.00057	0.00041	0.00582
13.416	0.022667	0.050633	0.0275949	0.0083038	0.01873	0.00155	0.0001	0.02038	0.00568	0.00041	3.5E-05	0.00612
18	0.030333	0.067759	0.0369285	0.0111124	0.02386	0.00127	0.00011	0.02524	0.00721	0.00336	3.3E-05	0.0106
Total	**0.4477**	**1**	**0.545**	**0.164**	**0.1001**	**0.0573**	**0.0806**	**0.238**	**0.0309**	**0.0192**	**0.0277**	**0.0778**

Fuel: JP-8			Total Particle Inhaled while Sleeping:					1.1538 mg				
Heater: AWHR-1101			Total Particle Inhaled while Rest:					0.3461 mg				
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
µm	mg		mg	mg	mg				mg			
0.0237	0.0695	0.178893	0.2064069	0.0619149	0.01738	0.07521	0.05447	0.14706	0.00495	0.02186	0.01924	0.04605
0.0748	0.028	0.072072	0.0831568	0.0249441	0.00299	0.01159	0.02211	0.0367	0.00086	0.00323	0.00755	0.01164
0.1342	0.0495	0.127413	0.1470093	0.0440977	0.00353	0.01197	0.02784	0.04334	0.00102	0.00329	0.00954	0.01385
0.24	0.0775	0.199485	0.230166	0.0690418	0.00373	0.01126	0.02951	0.04449	0.00108	0.00307	0.01016	0.01432
0.4233	0.0575	0.148005	0.1707683	0.0512246	0.0048	0.00558	0.01634	0.02673	0.0017	0.00152	0.00567	0.00888
0.7483	0.023	0.059202	0.0683073	0.0204898	0.00555	0.00191	0.00662	0.01407	0.00195	0.00052	0.00231	0.00477
1.3416	0.0195	0.050193	0.0579127	0.0173718	0.01206	0.00213	0.00848	0.02267	0.00411	0.00057	0.0029	0.00758
2.4	0.013	0.033462	0.0386085	0.0115812	0.01558	0.00237	0.00831	0.02626	0.00506	0.00063	0.00269	0.00838
4.2332	0.008	0.020592	0.0237591	0.0071269	0.01378	0.00213	0.00418	0.02009	0.0043	0.00056	0.00129	0.00615
7.4833	0.008	0.020592	0.0237591	0.0071269	0.01621	0.00225	0.00138	0.01983	0.00495	0.00058	0.00042	0.00596
13.416	0.012	0.030888	0.0356386	0.0106903	0.02419	0.002	0.00013	0.02632	0.00731	0.00053	4.5E-05	0.00788
18	0.023	0.059202	0.0683073	0.0204898	0.04413	0.00234	0.0002	0.04668	0.0133	0.00619	6.1E-05	0.01955
Total	**0.3885**	**1**	**1.1538**	**0.3461**	**0.1639**	**0.1307**	**0.1796**	**0.4742**	**0.0506**	**0.0425**	**0.0619**	**0.155**

Table AII4. Mouth breather dosimetry for 1-K kerosene.

Fuel: 1-K			Total Particles Inhaled while Sleeping:				1.332 mg					
Heater: OMNI-105			Total Particles Inhaled while Resting:				0.3996 mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.064	0.129817	0.1729168	0.0518751	0.01478	0.06284	0.04551	0.12313	0.00422	0.01826	0.01608	0.03856
0.0748	0.036	0.073022	0.0972657	0.0291797	0.00351	0.01355	0.02584	0.0429	0.00101	0.00378	0.00882	0.01361
0.1342	0.052	0.105477	0.1404949	0.0421485	0.00338	0.01143	0.02659	0.0414	0.00098	0.00314	0.00911	0.01323
0.24	0.074	0.150101	0.1999351	0.0599805	0.00326	0.00977	0.02562	0.03865	0.00095	0.00267	0.00883	0.01245
0.4233	0.048	0.097363	0.1296876	0.0389063	0.00305	0.00425	0.01243	0.01973	0.00105	0.00115	0.00431	0.00652
0.7483	0.05	0.10142	0.1350913	0.0405274	0.0082	0.00381	0.01321	0.02521	0.00286	0.00103	0.00461	0.0085
1.3416	0.024	0.048682	0.0648438	0.0194531	0.00983	0.00245	0.00978	0.02206	0.00335	0.00066	0.00336	0.00737
2.4	0.023	0.046653	0.062142	0.0186426	0.01832	0.00416	0.01458	0.03705	0.00597	0.00113	0.00479	0.01189
4.2332	0.008	0.016227	0.0216146	0.0064844	0.0094	0.00242	0.00474	0.01657	0.00296	0.00066	0.00151	0.00513
7.4833	0.029	0.058824	0.0783529	0.0235059	0.04282	0.01192	0.0073	0.06204	0.01329	0.00325	0.00234	0.01888
13.416	0.017	0.034483	0.045931	0.0137793	0.02817	0.00528	0.00035	0.0338	0.00867	0.00139	0.00012	0.01018
18	0.068	0.137931	0.1837241	0.0551172	0.11368	0.01214	0.00045	0.12627	0.03469	0.01348	0.00014	0.04831
Total	**0.493**	**1**	**1.332**	**0.3996**	**0.2584**	**0.144**	**0.1864**	**0.5888**	**0.08**	**0.0506**	**0.064**	**0.1946**

Fuel: 1-K			Total Particle Inhaled while Sleeping:				0.8732 mg					
Heater: RMC-95			Total Particle Inhaled while Rest:				0.262 mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.067	0.154734	0.1351141	0.0405404	0.01155	0.0491	0.03556	0.09621	0.0033	0.01427	0.01257	0.03014
0.0748	0.025	0.057737	0.0504157	0.015127	0.00182	0.00702	0.01339	0.02223	0.00052	0.00196	0.00457	0.00706
0.1342	0.033	0.076212	0.0665487	0.0199677	0.0016	0.00541	0.0126	0.01961	0.00046	0.00149	0.00432	0.00627
0.24	0.052	0.120092	0.1048647	0.0314642	0.00171	0.00512	0.01344	0.02027	0.0005	0.0014	0.00463	0.00653
0.4233	0.018	0.04157	0.0362993	0.0108915	0.00085	0.00119	0.00348	0.00552	0.0003	0.00032	0.00121	0.00183
0.7483	0.035	0.080831	0.070582	0.0211778	0.00428	0.00199	0.0069	0.01317	0.00149	0.00054	0.00241	0.00444
1.3416	0.019	0.04388	0.0383159	0.0114965	0.00581	0.00145	0.00578	0.01303	0.00198	0.00039	0.00199	0.00436
2.4	0.03	0.069284	0.0604988	0.0181524	0.01783	0.00405	0.01419	0.03607	0.00581	0.0011	0.00467	0.01157
4.2332	0.017	0.039261	0.0342827	0.0102864	0.01491	0.00384	0.00752	0.02627	0.00469	0.00105	0.00239	0.00813
7.4833	0.046	0.106236	0.0927649	0.0278337	0.0507	0.01411	0.00864	0.07345	0.01573	0.00385	0.00277	0.02236
13.416	0.045	0.103926	0.0907483	0.0272286	0.05566	0.01043	0.00069	0.06677	0.01713	0.00275	0.00024	0.02011
18	0.046	0.106236	0.0927649	0.0278337	0.0574	0.00613	0.00023	0.06375	0.01752	0.00681	6.9E-05	0.02439
Total	**0.433**	**1**	**0.8732**	**0.262**	**0.2241**	**0.1098**	**0.1224**	**0.4564**	**0.0694**	**0.0359**	**0.0418**	**0.1472**

Fuel: 1-K			Total Particle Inhaled while Sleeping:				1.469 mg					
Heater: AWHR-1101			Total Particle Inhaled while Rest:				0.441 mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.085	0.141667	0.2081083	0.062475	0.01779	0.07563	0.05477	0.14819	0.00508	0.02199	0.01936	0.04644
0.0748	0.128	0.213333	0.3133867	0.09408	0.01132	0.04365	0.08324	0.13821	0.00326	0.01218	0.02845	0.04389
0.1342	0.051	0.085	0.124865	0.037485	0.003	0.01016	0.02363	0.03679	0.00087	0.0028	0.0081	0.01177
0.24	0.068	0.113333	0.1664867	0.04998	0.00272	0.00814	0.02133	0.03219	0.00079	0.00222	0.00735	0.01037
0.4233	0.046	0.076667	0.1126233	0.03381	0.00265	0.00369	0.01079	0.01714	0.00092	0.001	0.00375	0.00567
0.7483	0.036	0.06	0.08814	0.02646	0.00535	0.00248	0.00862	0.01645	0.00187	0.00067	0.00301	0.00555
1.3416	0.012	0.02	0.02938	0.00882	0.00445	0.00111	0.00443	0.00999	0.00152	0.0003	0.00153	0.00334
2.4	0.024	0.04	0.05876	0.01764	0.01732	0.00393	0.01379	0.03504	0.00564	0.00107	0.00454	0.01125
4.2332	0.049	0.081667	0.1199683	0.036015	0.05217	0.01344	0.02633	0.09194	0.01642	0.00367	0.00839	0.02847
7.4833	0.044	0.073333	0.1077267	0.03234	0.05888	0.01639	0.01003	0.0853	0.01828	0.00447	0.00322	0.02598
13.416	0.017	0.028333	0.0416217	0.012495	0.02553	0.00478	0.00032	0.03063	0.00786	0.00126	0.00011	0.00923
18	0.04	0.066667	0.0979333	0.0294	0.0606	0.00647	0.00024	0.06731	0.01851	0.00719	7.3E-05	0.02577
Total	**0.6**	**1**	**1.469**	**0.441**	**0.2618**	**0.1899**	**0.2575**	**0.7092**	**0.081**	**0.0588**	**0.0879**	**0.2277**

Table AII5. Mouth breather dosimetry for JA-1 Jet Fuel.

Fuel: JA-1			Total Particles Inhaled while Sleeping:				**1.1582** mg					
Heater: OMNI-105			Total Particles Inhaled while Resting:				**0.3475** mg					
Mean Size	Sample Weight	Weight Frction	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
			Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.057	0.12311	0.1425862	0.0427808	0.01219	0.05182	0.03753	0.10153	0.00348	0.01506	0.01326	0.0318
0.0748	0.032	0.069114	0.0800484	0.0240173	0.00289	0.01115	0.02126	0.0353	0.00083	0.00311	0.00726	0.01121
0.1342	0.069	0.149028	0.1726043	0.0517873	0.00415	0.01404	0.03267	0.05086	0.0012	0.00386	0.01119	0.01626
0.24	0.084	0.181425	0.210127	0.0630454	0.00343	0.01027	0.02693	0.04062	0.001	0.0028	0.00928	0.01308
0.4233	0.064	0.138229	0.1600968	0.0480346	0.00377	0.00524	0.01535	0.02436	0.0013	0.00142	0.00533	0.00805
0.7483	0.03	0.064795	0.0750454	0.0225162	0.00455	0.00211	0.00734	0.014	0.00159	0.00057	0.00256	0.00472
1.3416	0.024	0.051836	0.0600363	0.018013	0.0091	0.00227	0.00905	0.02042	0.0031	0.00061	0.00312	0.00683
2.4	0.019	0.041037	0.0475287	0.0142603	0.01401	0.00318	0.01115	0.02834	0.00456	0.00086	0.00367	0.00909
4.2332	0.006	0.012959	0.0150091	0.0045032	0.00653	0.00168	0.00329	0.0115	0.00205	0.00046	0.00105	0.00356
7.4833	0.019	0.041037	0.0475287	0.0142603	0.02598	0.00723	0.00443	0.03763	0.00806	0.00197	0.00142	0.01145
13.416	0.02	0.043197	0.0500302	0.0150108	0.03069	0.00575	0.00038	0.03681	0.00945	0.00151	0.00013	0.01109
18	0.039	0.084233	0.097559	0.0292711	0.06037	0.00645	0.00024	0.06705	0.01842	0.00716	7.3E-05	0.02565
Total	**0.463**	**1**	**1.1582**	**0.3475**	**0.1777**	**0.1212**	**0.1696**	**0.4684**	**0.0551**	**0.0394**	**0.0583**	**0.1528**

Fuel: JA-1			Total Particle Inhaled while Sleeping:				**1.005** mg					
Heater: RMC-95			Total Particle Inhaled while Rest:				**0.3015** mg					
Mean Size	Sample Weight	Weight Frction	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
			Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.035	0.071575	0.0719325	0.0215798	0.00615	0.02614	0.01893	0.05122	0.00176	0.0076	0.00669	0.01604
0.0748	0.036	0.07362	0.0739877	0.0221963	0.00267	0.01031	0.01965	0.03263	0.00077	0.00287	0.00671	0.01036
0.1342	0.059	0.120654	0.1212577	0.0363773	0.00291	0.00986	0.02295	0.03573	0.00085	0.00271	0.00786	0.01142
0.24	0.065	0.132924	0.133589	0.0400767	0.00218	0.00653	0.01712	0.02583	0.00064	0.00178	0.0059	0.00832
0.4233	0.056	0.114519	0.115092	0.0345276	0.00271	0.00377	0.01103	0.01751	0.00094	0.00102	0.00383	0.00579
0.7483	0.026	0.05317	0.0534356	0.0160307	0.00324	0.00151	0.00522	0.00997	0.00113	0.00041	0.00182	0.00336
1.3416	0.039	0.079755	0.0801534	0.024046	0.01215	0.00303	0.01208	0.02726	0.00414	0.00082	0.00416	0.00911
2.4	0.012	0.02454	0.0246626	0.0073988	0.00727	0.00165	0.00579	0.01471	0.00237	0.00045	0.0019	0.00472
4.2332	0.028	0.05726	0.057546	0.0172638	0.02503	0.00645	0.01263	0.0441	0.00787	0.00176	0.00402	0.01365
7.4833	0.049	0.100204	0.1007055	0.0302117	0.05504	0.01532	0.00938	0.07974	0.01708	0.00418	0.00301	0.02427
13.416	0.038	0.07771	0.0780982	0.0234294	0.0479	0.00897	0.00059	0.05747	0.01474	0.00236	0.0002	0.01731
18	0.046	0.09407	0.0945399	0.028362	0.0585	0.00625	0.00023	0.06497	0.01785	0.00694	7.1E-05	0.02486
Total	**0.489**	**1**	**1.005**	**0.3015**	**0.2258**	**0.0998**	**0.1356**	**0.4611**	**0.0701**	**0.0329**	**0.0462**	**0.1492**

Fuel: JA-1			Total Particle Inhaled while Sleeping:				**1.142** mg					
Heater: AWHR-1101			Total Particle Inhaled while Rest:				**0.342** mg					
Mean Size	Sample Weight	Weight Frction	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
			Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.044	0.113695	0.1298398	0.0388837	0.0111	0.04719	0.03417	0.09246	0.00316	0.01369	0.01205	0.02891
0.0748	0.0455	0.117571	0.1342661	0.0402093	0.00485	0.0187	0.03567	0.05922	0.00139	0.00521	0.01216	0.01876
0.1342	0.074	0.191214	0.2183669	0.0653953	0.00525	0.01776	0.04133	0.06434	0.00152	0.00488	0.01414	0.02053
0.24	0.075	0.193798	0.2213178	0.0662791	0.00361	0.01082	0.02836	0.04279	0.00105	0.00295	0.00975	0.01375
0.4233	0.049	0.126615	0.1445943	0.0433023	0.0034	0.00474	0.01386	0.022	0.00117	0.00128	0.0048	0.00726
0.7483	0.0285	0.073643	0.0841008	0.025186	0.0051	0.00237	0.00822	0.01569	0.00178	0.00064	0.00286	0.00528
1.3416	0.0215	0.055556	0.0634444	0.019	0.00962	0.0024	0.00956	0.02158	0.00327	0.00065	0.00329	0.0072
2.4	0.014	0.036176	0.0413127	0.0123721	0.01218	0.00276	0.00969	0.02463	0.00396	0.00075	0.00318	0.00789
4.2332	0.0095	0.024548	0.0280336	0.0083953	0.01219	0.00314	0.00615	0.02148	0.00383	0.00085	0.00195	0.00664
7.4833	0.01	0.02584	0.029509	0.0088372	0.01613	0.00449	0.00275	0.02336	0.00499	0.00122	0.00088	0.0071
13.416	0.01	0.02584	0.029509	0.0088372	0.0181	0.00339	0.00022	0.02171	0.00556	0.00089	7.6E-05	0.00653
18	0.006	0.015504	0.0177054	0.0053023	0.01096	0.00117	4.3E-05	0.01217	0.00334	0.0013	1.3E-05	0.00465
Total	**0.387**	**1**	**1.142**	**0.342**	**0.1125**	**0.1189**	**0.19**	**0.4214**	**0.035**	**0.0343**	**0.0652**	**0.1345**

Table AII6. Mouth breather dosimetry for JP-8 Jet Fuel.

Fuel: JP-8			Total Particles Inhaled while Sleeping:				1.451 mg					
Heater: OMNI-105			Total Particles Inhaled while Resting:				0.4353 mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.052	0.066496	0.0964859	0.0289458	0.00825	0.03506	0.02539	0.06871	0.00236	0.01019	0.00897	0.02152
0.0748	0.057	0.07289	0.1057634	0.031729	0.00382	0.01473	0.02809	0.04664	0.0011	0.00411	0.0096	0.0148
0.1342	0.152	0.194373	0.2820358	0.0846107	0.00678	0.02294	0.05338	0.0831	0.00197	0.00631	0.01829	0.02656
0.24	0.168	0.214834	0.3117238	0.0935171	0.00509	0.01523	0.03994	0.06027	0.00149	0.00416	0.01376	0.0194
0.4233	0.083	0.106138	0.1540064	0.0462019	0.00363	0.00505	0.01476	0.02343	0.00125	0.00137	0.00512	0.00775
0.7483	0.058	0.074169	0.1076189	0.0322857	0.00653	0.00303	0.01052	0.02008	0.00228	0.00082	0.00367	0.00677
1.3416	0.035	0.044757	0.0649425	0.0194827	0.00985	0.00245	0.00979	0.02209	0.00335	0.00066	0.00337	0.00738
2.4	0.05	0.063939	0.0927749	0.0278325	0.02735	0.00621	0.02177	0.05532	0.00891	0.00168	0.00716	0.01775
4.2332	0.045	0.057545	0.0834974	0.0250492	0.03631	0.00935	0.01833	0.06399	0.01142	0.00255	0.00583	0.0198
7.4833	0.05	0.063939	0.0927749	0.0278325	0.0507	0.01411	0.00864	0.07346	0.01573	0.00385	0.00277	0.02236
13.416	0.008	0.01023	0.014844	0.0044532	0.0091	0.00171	0.00011	0.01092	0.0028	0.00045	3.8E-05	0.00329
18	0.024	0.030691	0.044532	0.0133596	0.02756	0.00294	0.00011	0.03061	0.00841	0.00327	3.3E-05	0.01171
Total	**0.782**	**1**	**1.451**	**0.4353**	**0.195**	**0.1328**	**0.2308**	**0.5586**	**0.0611**	**0.0394**	**0.0786**	**0.1791**

Fuel: JP-8			Total Particle Inhaled while Sleeping:				0.545 mg					
Heater: RMC-95			Total Particle Inhaled while Rest:				0.164 mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.065	0.145197	0.0791325	0.0238124	0.00677	0.02876	0.02083	0.05635	0.00194	0.00838	0.00738	0.0177
0.0748	0.022667	0.050633	0.0275949	0.0083038	0.001	0.00384	0.00733	0.01217	0.00029	0.00107	0.00251	0.00387
0.1342	0.083333	0.18615	0.101452	0.0305287	0.00244	0.00825	0.0192	0.02989	0.00071	0.00228	0.0066	0.00958
0.24	0.067	0.149665	0.0815674	0.024545	0.00133	0.00399	0.01045	0.01577	0.00039	0.00109	0.00361	0.00509
0.4233	0.061333	0.137007	0.0746687	0.0224691	0.00176	0.00245	0.00716	0.01136	0.00061	0.00067	0.00249	0.00377
0.7483	0.025667	0.057334	0.0312472	0.0094028	0.0019	0.00088	0.00306	0.00583	0.00066	0.00024	0.00107	0.00197
1.3416	0.015667	0.034996	0.019073	0.0057394	0.00289	0.00072	0.00288	0.00649	0.00099	0.00019	0.00099	0.00218
2.4	0.014	0.031273	0.0170439	0.0051288	0.00502	0.00114	0.004	0.01016	0.00164	0.00031	0.00132	0.00327
4.2332	0.021	0.04691	0.0255659	0.0076932	0.01112	0.00286	0.00561	0.01959	0.00351	0.00078	0.00179	0.00608
7.4833	0.019	0.042442	0.023131	0.0069605	0.01264	0.00352	0.00215	0.01831	0.00393	0.00096	0.00069	0.00559
13.416	0.022667	0.050633	0.0275949	0.0083038	0.01693	0.00317	0.00021	0.0203	0.00523	0.00084	7.2E-05	0.00613
18	0.030333	0.067759	0.0369285	0.0111124	0.02285	0.00244	9E-05	0.02538	0.00699	0.00272	2.8E-05	0.00974
Total	**0.4477**	**1**	**0.545**	**0.164**	**0.0866**	**0.062**	**0.083**	**0.2316**	**0.0269**	**0.0195**	**0.0286**	**0.075**

Fuel: JP-8			Total Particle Inhaled while Sleeping:				1.1538 mg					
Heater: AWHR-1101			Total Particle Inhaled while Rest:				0.3461 mg					
Mean	Sample	Weight	Inhaled Particles		Deposition Value for Sleeping				Deposition Value for Rest			
Size	Weight	Frction	Sleeping	Rest	NOPL	TB	P	Total	NOPL	TB	P	Total
μm	mg		mg	mg	mg				mg			
0.0237	0.0695	0.178893	0.2064069	0.0619149	0.01765	0.07501	0.05432	0.14698	0.00504	0.0218	0.01919	0.04603
0.0748	0.028	0.072072	0.0831568	0.0249441	0.003	0.01158	0.02209	0.03667	0.00087	0.00323	0.00754	0.01164
0.1342	0.0495	0.127413	0.1470093	0.0440977	0.00353	0.01196	0.02783	0.04332	0.00102	0.00329	0.00953	0.01384
0.24	0.0775	0.199485	0.230166	0.0690418	0.00376	0.01125	0.02949	0.0445	0.0011	0.00307	0.01016	0.01433
0.4233	0.0575	0.148005	0.1707683	0.0512246	0.00402	0.00559	0.01637	0.02598	0.00139	0.00152	0.00568	0.00859
0.7483	0.023	0.059202	0.0683073	0.0204898	0.00414	0.00192	0.00668	0.01275	0.00145	0.00052	0.00233	0.0043
1.3416	0.0195	0.050193	0.0579127	0.0173718	0.00878	0.00219	0.00873	0.0197	0.00299	0.00059	0.003	0.00658
2.4	0.013	0.033462	0.0386085	0.0115812	0.01138	0.00258	0.00906	0.02302	0.00371	0.0007	0.00298	0.00738
4.2332	0.008	0.020592	0.0237591	0.0071269	0.01033	0.00266	0.00521	0.01821	0.00325	0.00073	0.00166	0.00563
7.4833	0.008	0.020592	0.0237591	0.0071269	0.01299	0.00361	0.00221	0.01881	0.00403	0.00099	0.00071	0.00572
13.416	0.012	0.030888	0.0356386	0.0106903	0.02186	0.00409	0.00027	0.02622	0.00673	0.00108	9.2E-05	0.0079
18	0.023	0.059202	0.0683073	0.0204898	0.04227	0.00451	0.00017	0.04695	0.0129	0.00501	5.1E-05	0.01796
Total	**0.3885**	**1**	**1.1538**	**0.3461**	**0.1437**	**0.137**	**0.1824**	**0.4631**	**0.0445**	**0.0425**	**0.0629**	**0.1499**